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(54) Title: ELECTRIC ARC MONITORING SYSTEMS

(57) Abstract

Electric arc monitoring is effected by exploiting the discovery that electric arcs are fractal phenomena in that all essential information that signifies "arc" is contained in each fractal subset. These fractal subsets are logarithmically distributed over the arc spectrum. Monitoring of arcs is most advantageously effected on a fractal subset (16) of low logarithmic order where the amplitude is higher pursuant to the 1/f characteristic of electric arcs, where cross–induction among neighboring circuits is lower, and where travel between the arc (12) and the arc signature pickup (23) is longer than at the high frequencies customary for electric arc detection. Fractal subset transformation (17) reduces the danger of false alarms. Arc signature portions may be processed in out of phase paths (242, 342) or treated as modulated carriers (42) for monitoring. Aircraft may be equipped with spark monitoring systems (80) that record (82–86) occurence of dangerous sparking at different locations (92–96) aboard the aircraft (81).

1   ## ELECTRIC ARC MONITORING SYSTEMS
2   ### Cross-Reference

3   This International application claims priority from its
4   commonly owned parent application, the International Application
5   No. PCT/US97/14497, filed 14 AUG 97, and having the same
6   inventorship.

7   ### Technical Field

8   The technical field of the invention includes methods and
9   apparatus for monitoring, detecting, indicating, evaluating and
10   signaling electric arcs or sparks.

11   ### Background

12   The chaotic electromagnetic emanations manifesting
13   themselves as electric arcs or sparks are closely linked to
14   matter, wherein electromagnetic interactions bind electrons to
15   nuclei in atoms and molecules and wherein the fundamental unit
16   of electromagnetic radiation is the photon.
17   Indeed, spectra of electric arcs and sparks extend
18   practically from DC through the entire radio-frequency spectrum
19   and through microwave, infrared and light spectra.
20   Useful exploitations of the electric arc and spark
21   phenomenon include the electric arc lamp, electric welding, the
22   electric-arc-type of metallurgical furnace, the arc type of ion
23   generator in satellite thrusters and for propulsion in outer
24   space, the spark-plug-type of ignition in internal combustion
25   engines, and electric spark ignition in gas appliances.
26   Unfortunately, the same quality of the electric arc or spark
27   that led to electric lighting, electric arc welding and
28   metallurgy, and ignition of internal combustion, has catastrophic
29   effects in electrical faults that cause explosions or devastating
30   fires through chaotic arcing or sparking.
31   A tragic example of this is seen in TWA flight 800 which on
32   17 July 1996 exploded over the Atlantic Ocean shortly after
33   taking off from John F. Kennedy Airport. That disaster,

1 including its loss of all 230 persons aboard, sparked the most
2 extensive governmental investigation in the history of aviation.
3 As a result, it became known that the disaster started as a
4 fuel/air explosion in the almost empty center fuel tank. After
5 theories of sabotage were discounted, the most likely cause
6 turned up as electric sparking or arcing in the fuel system.
7 Indeed, such kind of sparking or its potential were found on
8 other aircraft which thereupon were grounded for repair.
9   Conventional electric arc monitoring would, however, appear
10 to be of little use in this respect, inasmuch as it manifestly
11 is too late to recall an aircraft when an arc has sparked an
12 explosion in the fuel system. In consequence, more is needed,
13 or a different approach is required, than what the prior art
14 suggests in terms of arc detection in aircraft electric current
15 distribution systems in US Patents 5,185,684 by Beihoff et al.,
16 5,185,685 by Tennies et al., 5,185,686 by Hansen et al.,
17 5,185,687 by Beihoff et al., 5,206,596 by Beihoff et al., and
18 5,208,542 by Tennies et al., all issued to Eaton Corporation.
19   Electric arc detection aboard aircraft is also encumbered
20 by the kind of electrostatic charge phenomena mentioned in US
21 patents 3,857,066, by Cline et al., issued to Dayton Aircraft
22 Products, and disclosing electrostatic sensing probes, 4,262,254,
23 by Eliasz Poss, issued to United Technologies Corporation, and
24 disclosing a balanced corona electrostatic field sensor, and
25 4,323,946, by Robert L. Traux, disclosing techniques for reducing
26 electrostatic charge storage.
27   By way of further example, electric arc monitors would be
28 useful in garages, automobile or motorcar repair facilities,
29 gasoline (British "petrol") storage or dispensing facilities and
30 in other areas where accidental electric arcing can cause
31 disastrous explosions.
32   Moreover, fuses and circuit breakers are capable of
33 preventing serious overload conditions, but they are generally
34 ineffective to prevent electrical fires and other damage from
35 accidental arcs and sparks which typically generate enough heat
36 for a fire at electric current levels below the level at which
37 the fuse will blow or the circuit breaker will trip. Reliable

1   arc monitoring would thus be highly desirable in a large number
2   and variety of electrical circuits.
3   These are, of course, only representative examples of fields
4   where reliable arc or spark monitoring could be useful.
5   A major stagnating problem in this respect has been that
6   prior-art development has run its course in its fear of false
7   alarms. Of course, false alarms are the bane of alarm systems,
8   as frequent occurrence of false alarms can nullify the utility
9   of any alarm system.
10   Accordingly, in an effort to reduce the possibility of false
11   alarms arising from radio broadcast and radio frequency security
12   system signals, the arc detection system as disclosed in the
13   International Patent Publication WO90/04278, by HAMPSHIRE,
14   Michael John, rejects frequencies below about 160 kHz and above
15   some 180 kHz of the arc signal signature, leaving for electrical
16   fault detection only a narrow 20 kHz band at some 170 kHz center
17   frequency. This, however, left a sample for arc detection that
18   was dozens of times too small in the 100 kHz range for reliably
19   detecting the occurrence of an arc signature while at the same
20   time preventing the occurrence of false alarms equally reliably.
21   An arc detection system which avoids that drawback is
22   apparent from PCT/US90/06113, filed 24 October 1990 and published
23   as WO92/08143, by Hendry Mechanical Works, inventors HAM, Jr.,
24   Howard M., and KEENAN, James J., and in its corresponding US
25   Patents 5,373,241, issued 13 December 1994, and 5,477,150, issued
26   19 December 1995, all herewith incorporated by reference herein
27   for the United States of America and for all other countries
28   where incorporation by reference is permitted. Reference should
29   also be had to their corresponding EPO 507 782 (90917578.8) and
30   resulting European national patents, and to their corresponding
31   Australian Patent 656128, Canadian Patent Application 2,093,420,
32   Chinese Patent Application 92102453.3, Japanese Patent
33   Application 500428/91, Korean Patent Application (PCT) 701219/93,
34   and Mexican Patent 178914(9201530), all herewith incorporated by
35   reference herein for all countries where incorporation by
36   reference is permitted. That system avoids false alarms by
37   converting instantaneous arc signature frequencies into a

1   combination frequency from which arc-indicative signals are
2   detected in contradistinction to extraneous narrow-band signals
3   that could cause false alarms.

4   Against this background, a frequency selective arc detection
5   system of a subsequently filed prior-art application, appears as
6   a typical representative of the prior-art approach to arc
7   detection. It accordingly presents a variety of approaches to
8   arc detection that mainly look at frequencies in the upper
9   kilohertz range, such as from 100 kHz to one megahertz. This,
10   however, covers not only major portions of the public A.M. radio
11   broadcast band, also known as "long-wave" and "medium-wave"
12   broadcast bands in some countries, but also the kind of control
13   or security systems radio frequency band referred to in the above
14   mentioned WO90/04278 reference. Depending on location, one thus
15   had to contend with dozens of extraneous signal interferences.

16   The same in essence applies to another embodiment in that
17   prior-art proposal that suggests using a comb filter arrangement
18   composed of four bandpass filters each of which has a 50 kHz
19   passband, and three of which have a center frequency of 225 kHz,
20   525 kHz, and 825 kHz, respectively. In the A.M. broadcast and
21   above mentioned control and security systems radio frequency band
22   portion of that spectrum, 50 kHz samples can only represent minor
23   fragments of the chaotic arc signature, raising the danger of
24   false alarms from coincidental extraneous signals. This also
25   affects the efficacy of the 55 kHz bandpass filter in that comb
26   filter arrangement, inasmuch as that prior-art proposal
27   continuously rotates its detection process among the four filter
28   components of that comb filter arrangement.

29   A prior effort at arc detection that ventured into low
30   frequency regions effected monitoring in various low frequency
31   bands that were too narrow for reliable arc detection as apparent
32   from US Patent 5,578,931 and articles by B. D. Russell et al.,
33   entitled "An Arcing Fault Detection Technique Using Low Frequency
34   Current Components - Performance Evaluation Using Recorded Field
35   Data" and "Behaviour of Low Frequency Spectra During Arcing Fault
36   and Switching Events" (IEEE Transactions on Power Delivery, Vol.
37   3, No. 4, October 1988, pp. 1485 - 1500) indicating lack of

1   success.

2   These developments in retrospect appear largely as a
3 reaction to the perception of electric arcs as highly random
4 phenomena borne out of the chaotic nature of arc signatures.
5 This prior-art perception, however, ignores the fact that chaotic
6 systems have a deterministic quality, and can be successfully
7 dealt with, if one is able to discover what the underlying
8 principles are and how they can be put to effective use.

9   Indeed, even chaotic electric lightning displays some self-
10 similarity among its arboresque nocturnal discharges and within
11 the branched configuration of its lightning bolts.

12   In this respect, pioneering work done by Benjamin Franklin
13 and by Georg Christoph Lichtenberg back in the 18th Century casts
14 a long shadow all the way to the subject invention.

15   In particular, Franklin through his famous kite experiment
16 in a thunderstorm proved that lightning is an electrical
17 phenomenon.   Lichtenberg thereafter created his famous
18 "Lichtenberg figures" in 1777 by dusting fine powder, such as
19 sulfur, over insulating surfaces over which electrical discharges
20 had taken place. Many of these Lichtenberg figures of electrical
21 discharge resemble lightning in appearance and otherwise display
22 a striking self-similarity in their patterns of branching lines
23 and within such branching lines themselves. Manfred Schroeder
24 compared this to diffusion-limited aggregation (DLA) in his book
25 entitled "FRACTALS, CHAOS, POWER LAWS" (W.H. Freeman and Company,
26 1991), pp. 196, 197, 215 and 216. Kenneth Falconer, in his book
27 entitled "FRACTAL GEOMETRY" (John Wiley & Sons, 1990), pp. 270
28 to 273, also applied the DLA model to electrical discharges in
29 gas.

30   By way of background, fractals are phenomena in the fractal
31 geometry conceived, named and first explained by Benoit
32 Mandelbrot in 1975.   Fractal geometry in effect is a
33 manifestation of the fact that the natural world does not conform
34 to an Euclidean type of geometry. Euclidean geometry is based
35 on characteristic sizes and scaling. The natural world is not
36 limited to specific size or scaling. Euclidean geometry suits
37 man-made objects, but cannot realistically express natural

1 configurations. Euclidean geometry is described by formulas,
2 whereas the mathematical language of natural phenomena is
3 recursive algorithms.

4 Such recursiveness is an expression of nature throughout
5 destructive if not chaotic influences, manifesting itself, for
6 instance, in a persistent invariance against changes in size and
7 scaling, generating almost endless, repetitious patterns of self-
8 similarity or self-affinity. Fractals are self-similar in that
9 each of various small portions of a fractal represents a
10 miniature replica of the whole. Such small portions are herein
11 called "fractal subsets". This is the way nature works, and the
12 electric arc or spark is no exception to that intrinsic
13 principle.

14 Electric arc or spark monitoring generally addresses itself
15 to so-called arc signatures which are part of the electromagnetic
16 spectrum of arcs or sparks situated in frequency bands way below
17 light, heat radiation and microwave spectra.

18 Problems in this area include false alarms from mutual
19 induction among neighboring monitored circuits. In this respect,
20 reference may be had to a standard equation for mutual induction,
21 such as between a monitored circuit in which an arc is occurring,
22 and a neighboring monitored circuit in which no arc is occurring
23 at the time:

24
$$I_n = 2\pi f M I_{aa}/Z_n \tag{1}$$

25 wherein: I_{aa} = arc signature current flowing in the monitored
26 circuit where an electric arc occurs at the
27 moment,
28 I_n = current induced by the arc signature in a moni-
29 tored neighboring circuit where no arc has
30 occurred at the moment,
31 M = mutual inductance,
32 Z_n = impedance of said neighboring circuit, and
33 f = frequency.

34 As between neighboring circuits, the current I_n induced in

1   a neighboring monitored circuit by current I_{aa} flowing in the
2   monitored circuit where an arc is occurring, decreases with
3   decreasing frequency of that primary current I_{aa}. However,
4   electromagnetic arc signatures are characterized by a special
5   shape approximating an inverse frequency (1/f) progression of
6   their amplitude. If this is put into the above Equation (1) one
7   gets

8                    $$I_n = (2\pi fMI_{aa}/f)/Z_n \qquad (2)$$
9   in which "f" would cancel out, so that one gets

10                   $$I_n = 2\pi MI_{aa}/Z_n \qquad (3)$$

11 that is, a mutual inductance and a secondary current, I_n, that
12 are independent of frequency. Such considerations have led to
13 the prior-art conclusion that lowering the frequency of arc
14 signature bands in which arcs are monitored would not effectively
15 reduce cross-induction and false arc alarms therefrom.

1   Summary of Invention

2   It is a general object of the invention to provide improved
3   electric arc monitoring systems that employ novel circuitry
4   and/or take advantage of properties of electric arc signatures
5   not heretofore utilized.

6   It is a related object of embodiments of the invention to
7   permit reliable arc monitoring at distances from electric arcs
8   longer and with less cross-talk or induction than heretofore.

9   It is a germane object of aspects of the invention to
10 exploit and to utilize the discovery herein expounded that the
11 electric spark or arc is a totally holistic phenomenon of a
12 fractal nature over its entire electromagnetic spectrum extending
13 from extremely low frequencies [ELF] through the radio frequency
14 band to its visible manifestations, including the previously
15 mentioned branched nocturnal and other visible discharges, and
16 discharge patterns including those manifested in the above
17 mentioned "Lichtenberg figures".

18   In this respect an aspect of the subject invention
19 accordingly exploits the discovery that electric arcs are fractal
20 phenomena not only in the visible luminous portion of their
21 electromagnetic radiation, as heretofore thought, but in fact are
22 fractal phenomena all the way down to the extremely low frequency
23 band of their electromagnetic emanation into space or along wires
24 of the circuit where the particular arc occurs. Since all
25 essential information that signifies "arc" is thus contained in
26 each fractal subset, it is sufficient for arc monitoring purposes
27 to monitor a fractal subset of the arc's electromagnetic
28 emanation.

29   Expressions such as "monitor" and "monitoring" are herein
30 used in a broad sense, including monitoring, detecting,
31 indicating, evaluating and/or signaling electric arcs or sparks,
32 whereas the word "arc" is herein used generically to cover
33 electric arcs and sparks interchangeably as being essentially the
34 same phenomenon, except where otherwise noted herein.

35   The realization according to the subject invention that the

1   fractal nature of the arc is not limited to its visible region,
2   but in fact extends all the way down to a few cycles per second
3   of its signature, adds to the previously known characteristics
4   of electric arcs at least one fundamental characteristic and at
5   least one criterion; namely, that:

6   1. All essential information for effective electric
7   arc monitoring is contained in any fractal subset
8   of the arc signature; whereby

9   2. the selection of the monitoring frequency band for
10   each purpose is liberated from prior-art con-
11   straints and can truly be the result of an optimum
12   tradeoff in sensitivity, speed of detection,
13   prevention or rejection of false signals, desired
14   length of travel and mode of transmission of the
15   arc signature from the arc to the monitoring
16   circuit in different environments.

17   Pursuant to these principles, the subject invention resides
18   in a system of monitoring an electric arc having an arc signature
19   typified by a wideband range of frequencies of a chaotic nature
20   in a monitored circuit, and, more specifically, resides in
21   selecting a fractal subset of the arc signature characterized by
22   relatively long travel along the monitored circuit, and
23   monitoring that fractal subset of the arc signature.
24   The expression "relatively" in this context refers to the
25   fact that the length of possible travel of the arc signal is
26   inversely proportional to the frequency of the arc signature.
27   In this respect, reference may be had to the familiar algebraic
28   equation for electric current:

29 $$I = E/[R^2 + (2\pi fL - 1/2\pi fC)^2]^{\frac{1}{2}} \qquad (4)$$

30 wherein: I = electric current,
31   E = voltage or potential,
32   R = resistance,

1 f = frequency,

2 L = inductance, and

3 C = capacitance of the electric circuit.

4 From this equation a related benefit of an embodiment of the
5 invention can be seen; namely, that a selection of the lowest
6 frequency or longest wavelength fractal in effect amounts to a
7 selection of the longest survivor of the different fractals of
8 the arc signature traveling along the monitored circuit. Up to
9 a point, one can say that the monitored circuit itself thus
10 performs the function of a low-pass filter for the arc detection
11 monitor. Accordingly, embodiments of the invention permit arc
12 monitoring at considerable distances from the occurrence cf arcs
13 in the circuit, which is useful in practice for several reasons,
14 including the capability of surveying large circuits, and the
15 convenience of providing central arc detection monitoring
16 stations for several different circuits.

17 At any rate, at low arc signature frequencies, the possible
18 travel of the arc signal along the monitored circuit is long,
19 relative to higher arc signature frequencies.

20 It also turns out that false alarms from mutual induction
21 among neighboring monitored circuits is lowest at low arc
22 signature frequencies, quite contrary to what the prior art would
23 have indicated pursuant to Equations (1) to (3) set forth above,
24 wherein the frequency factor "f" in the denominator would cancel
25 out the "f" in the numerator in Equation (2).

26 However, the fallacy of that conclusion becomes apparent if
27 certain possible radiation effects are considered. In this
28 respect, it is well known that $\lambda/2$ and $\lambda/4$ antennas constitute
29 excellent Hertzian and Marconi-type electromagnetic radiators.
30 The wiring in many telephone exchange, electric power supply and
31 other installations in effect often forms such antennas at the
32 kind of radio frequencies selected by the prior art for electric
33 arc detection purposes. Even where the length of some wiring in
34 an installation in insufficient to constitute a quarter-wave-
35 length antenna, certain reactances in the circuit can provide the
36 lumped-impedance kind of tuning or "loading" that renders even

relatively short conductors effective radiators.

In consequence, picked-up electromagnetic arc signatures are transmitted among neighboring circuits, resulting in false alarms, unless the segment of the arc signature picked up for monitoring is of a very low frequency (VLF) according to one aspect of the invention.

Accordingly, lower frequency fractals pursuant to embodiments of the invention induce less spurious signals through cross-induction in neighboring circuits than arc signatures having higher frequencies. Low frequency fractals more effectively avoid false alarms from mutual inductance among neighboring circuits than arc signatures at higher frequencies.

In consequence, embodiments of the invention not only permit arc monitoring at considerable distances from the occurrence of arcs in a monitored circuit, but also avoid false alarms in neighboring monitored circuits.

According to a related embodiment of the invention, the electric arc is detected from a fractal subset of the arc signature at frequencies below 30 kHz. According to The New IEEE Standard Dictionary of Electrical and Electronics Terms, Fifth Edition (The Institute of Electrical and Electronics Engineers, 1993), this is the upper limit of the very low frequency (VLF) band.

A presently preferred embodiment of the invention restricts fractal subsets from which the electric arc is detected to the ELF (extremely low frequency) band which in that IEEE Standard Dictionary is defined as extending from 3 Hz to 3 kHz.

Another embodiment of the invention restricts monitored fractals to arc signature frequencies below the voice frequency band (vf) defined in that IEEE Standard Dictionary as extending from 200 Hz to 3500 Hz.

In that vein, a further embodiment of the invention restricts monitored fractal subsets to arc signature frequencies below a first harmonic of a standard line frequency in alternating-current power supply systems.

An embodiment of the invention even selects the monitored arc signature fractal subset from a frequency band on the order

1 of a standard line frequency in alternating-current power supply
2 systems.
3   According to a related aspect of the invention, an apparatus
4 for monitoring an electric arc having an arc signature typified
5 by a wideband range of frequencies of a chaotic nature in a
6 monitored circuit, comprises, in combination, an electric filter
7 having an input coupled to that arc, having a passband
8 corresponding to a fractal subset of the arc signature
9 characterized by relatively long travel along the monitored
10 circuit, and having an output for that fractal subset of arc
11 signature. Such apparatus includes a chaotic wideband signal
12 detector having a detector input for that fractal subset of the
13 arc signature coupled to the output of the electric filter.

14   From another aspect thereof, the invention resides in a
15 method of monitoring an electric arc having an arc signature
16 extending over a wideband range of frequencies of a chaotic
17 nature in a monitored circuit. The invention according to this
18 aspect resides, more specifically, in the improvement comprising,
19 in combination, processing portions of the arc signature in two
20 paths out of phase with each other, and monitoring the electric
21 arc from such out of phase portions of the arc signature.

22   From a related aspect thereof, the invention resides in
23 apparatus for monitoring an electric arc having an arc signature
24 typified by a wideband range of frequencies of a chaotic nature
25 in a monitored circuit. The invention according to this aspect
26 resides, more specifically, in the improvement comprising, in
27 combination, an electric filter having an input coupled to the
28 arc, having a passband corresponding to portions of the arc
29 signature, and having an output for such portions of arc
30 signature, an inverting amplifier having an input connected to
31 the output of the electric filter, and having an amplifier
32 output, a non-inverting amplifier having an input connected to
33 the output of the electric filter, having an amplifier output,
34 and being in parallel to said inverting amplifier, and a chaotic
35 wideband signal detector having a detector input coupled to the
36 amplifier outputs of the inverting and non-inverting amplifiers.

1   From another aspect thereof, the invention resides in a
2 method of monitoring an electric arc having an arc signature
3 extending over a wideband range of frequencies of a chaotic
4 nature in a monitored circuit, and, more specifically, resides
5 in the improvement comprising, in combination, treating the arc
6 signature as a modulated carrier having a modulation indicative
7 of the electric arc, and monitoring the electric arc by
8 monitoring a modulation of the modulated carrier.

9   From a related aspect thereof, the invention resides in
10 apparatus for monitoring an electric arc having an arc signature
11 typified by a wideband range of frequencies of a chaotic nature
12 in a monitored circuit, and, more specifically, resides in the
13 improvement comprising, in combination, a modulated carrier
14 detector having an arc signature input and a carrier modulation
15 output.

16   From a similar aspect thereof, the invention resides in
17 apparatus for monitoring an electric arc having an arc signature
18 typified by a wideband range of frequencies of a chaotic nature
19 in a monitored circuit, and, more specifically, resides in the
20 improvement comprising, in combination, combined modulated
21 carrier detectors having arc signature inputs and a combined
22 carrier modulation output.

23   From another aspect thereof, the invention resides in a
24 method of monitoring occurrence of sparks aboard aircraft,
25 comprising, in combination, continually monitoring an occurrence
26 of sparks at a first location aboard the aircraft, continually
27 monitoring an occurrence of sparks at a second location aboard
28 the aircraft distant from that first location, and establishing
29 in response to such monitoring a record of sparks occurring at
30 the first location and a record of sparks occurring at the
31 distant second location aboard the aircraft.
32   The word "spark" is used generically in this respect to
33 cover sparks and electric arcs interchangeably, inasmuch as there
34 may be sparking aboard aircraft that is not of an electrical
35 origin, but that still has the potential of igniting fuel vapors

1 and causing other damage, such as more fully disclosed below.

2 Accordingly, from a related aspect thereof, the invention

3 resides in a spark monitoring system aboard aircraft, comprising,

4 in combination, a spark monitor at a first location aboard the

5 aircraft, having a first spark signal output, a spark monitor at

6 a second location aboard the aircraft distant from the first

7 location, having a second spark signal output, and a spark signal

8 recorder connected to the first and second spark signal outputs.

1 <u>Brief Description of the Drawings</u>

2   The subject invention and its various aspects and objects
3 will become more readily apparent from the following detailed
4 description of preferred embodiments thereof, illustrated by way
5 of example in the accompanying drawings which also constitute a
6 written description of the invention, wherein like reference
7 numerals designate like or equivalent parts, and in which:

8   Fig. 1 is a polar coordinate representation of an electric
9 arc signature spectrum in terms of wavelength and illustrates
10 selection of a fractal subset for arc monitoring pursuant to an
11 embodiment of the invention;

12   Fig. 2 is a block diagram of an electric arc monitoring
13 system pursuant to an embodiment of the invention;

14   Fig. 3 shows gain vs. frequency graphs illustrating a
15 presently preferred embodiment of the invention;

16   Fig. 4 is a schematic of circuitry that may be used in the
17 system of Fig. 2 or otherwise for monitoring an arc according to
18 an embodiment of the invention;

19   Fig. 5 is a schematic of another circuitry that may be used
20 in the system of Fig. 2 or otherwise for monitoring an arc
21 according to an embodiment of the invention;

22   Fig. 6 is a schematic of a further circuitry that may be
23 used in the system of Fig. 2 or otherwise for monitoring the arc
24 also according to an embodiment of the invention;

25   Fig. 7 is a circuit diagram of an optical indicator of
26 possible or actual arcing that can be used at various stages in
27 the systems of Figs. 2, 4, 5 and 6, according to a further
28 embodiment of the invention; and

29   Fig. 8 is a schematic view of a spark monitoring system in
30 and for aircraft pursuant to an embodiment of the invention.

31   The accompanying Fig. 1 is copyright © as an original
32 creation under the Berne Convention and all corresponding
33 national laws, with Hendry Mechanical Works, of Goleta,
34 California, United States of America, being the copyright
35 proprietor which understands that this figure will be published
36 by the World Intellectual Property Organization and thereafter
37 by patent offices throughout the world.

Modes of Carrying Out the Invention

1

2   The drawings illustrate some basic modes and also preferred
3 modes of carrying out an aspect of the invention. Since fractal
4 geometry is a visual art as much as a mathematical science, Fig.
5 1 shows the workings of the invention in terms of a logarithmic
6 spiral. This is a novel aspect, since arc signature spectra
7 traditionally have been plotted in Cartesian coordinates and in
8 terms of frequency. To a large extent, thinking and plotting in
9 terms of frequency was justified, since the frequency of the arc
10 signature is largely independent of the medium through which it
11 travels, while the wavelength of the arc signature depends more
12 directly on the traversed medium.

13   The traditional focus of the prior art on frequency _ab_
14 _initio_ obstructed visualization of arc signatures as a
15 logarithmic phenomenon of fractal nature, whereas thinking and
16 plotting in terms of wavelength according to the currently
17 discussed aspect of the invention, leads to visualization,
18 graphic representation and beneficial exploitation of that
19 phenomenon.

20   In this vein, the polar coordinate representation of Fig.
21 1 arises from the basic equation

22
$$r = \exp(q\lambda_v) \tag{5}$$

23 wherein: r = radius,
24 q = growth factor larger than 1, and
25 λ_v = polar angle in terms of wavelength in the particular
26   medium, such as monitored circuit wires.

27   The polar coordinate plot of Fig. 1 represents a logarithmic
28 growth spiral occurring in innumerable natural objects, including
29 the spiral ammonite that appeared on the earth during the
30 Devonian period which also brought forth algae and the first
31 terestial plants some 380 million years ago. These developed in
32 the subsequent Carboniferous period some 260 million years ago
33 to ferns that have very pronounced fractal structures wherein
34 each leaf structure is a miniature replica of the branch
35 structure, and wherein each branch is a replica of the fern plant
36 or bush. Ammonites became extinct at the end of the Cretaceous

1   period some 65 million years ago, but ferns are very much alive

2   along with millions of natural objects of fractal structure.

3   Fortunately for the insight needed in the subject invention,

4   the area where the pioneering mathematician Jacob Bernoulli lived

5   until 1705, had been a marine environment millions of years

6   earlier.   This provided that region with an abundance of

7   petrified logarithmically spiraled ammonites, along with a

8   plethora of other petrifications.

9   Bernoulli was so fascinated by the logarithmic spiral that

10   he devoted his famous treaty entitled "Spira Mirabilis"

11   (Wonderful Spiral) to the same. One of such wondrous properties

12   is that the logarithmic spiral is the perfect fractal in that it

13   persists through various changes. To magnification and reduction

14   it responds elegantly by rotational displacement, thereby

15   preserving its shape unaffected.   This and other well-known

16   properties of logarithmic spirals reveals them as truly fractal

17   phenomena to which the electric arc signature seems akin, if

18   viewed in polar coordinates in terms of wavelength, such as in

19   Fig. 1.

20   In this respect, the ammonite shell had a chambered

21   structure wherein internal chambers were partitioned off by

22   septa, which were a series of spaced plates which were spaced

23   most closely at the center of the shell and the spacing of which

24   increased logarithmically along the growth spiral of the shell.

25   Accordingly, the size of the chambers between adjacent septa

26   increased logarithmically along the growth spiral.

27   In analogy to ammonite shell chambers, the size of frequency

28   or wavelength intervals 12 between indicated wavelengths or

29   frequencies 13 also increases logarithmically in terms of

30   wavelength in the electric arc signature or spectrum 10.

31   The core of the electromagnetic arc emanation has been

32   labelled as $<\mu$ at the pole of Fig. 1, indicating wavelengths of

33   less than one micron; that is, signifying the familiar visible

34   light emitted by the arc. In the subsequent logarithmic turn,

35   the symbol $>\mu$ has been shown to indicate infrared radiation and

36   microwaves that can be responsible for the utility of electric

37   arcs in electric welding, metallurgical furnaces, and internal

1 combustion engine ignition, and contrariwise in the sparking of

2 explosions and startup of devastating fires by electric arcs.

3 Thereafter, Fig. 1 indicates specific portions of the

4 electromagnetic arc signature in terms of frequency, including

5 the following frequency bands with increasing progression:

6 GHz = gigahertz,

7 MHz = megahertz range wherein arc signature detection has

8 been conducted by the prior art and wherein extraneous

9 signals from television broadcasts and radio signals

10 abound,

11 100 kHz = the one-hundred kilohertz range wherein arc

12 signature detection also has been conducted

13 extensively by the prior art and wherein radio

14 broadcast signals abound,

15 30 kHz = a lower limit of prior-art arc detection,

16 VLF = "very low frequency" defined as extending from 3 kHz

17 to 30 kHz by the above mentioned IEEE Dictionary.

18 ELF = "extremely low frequency" defined as extending from

19 3 Hz to 3 kHz by that IEEE Dictionary,

20 vf = "voice frequency" within the range of 200 to 3500 Hz

21 according to that IEEE Dictionary, and

22 ℓf = "line frequency", i.e. 50 Hz in European Systems, or

23 60 Hz in American systems.

24 Of course, no patent drawing can actually depict the chaotic

25 nature of electric arcs. Rather, Fig. 1 as a minimum has to be

26 viewed in terms of an instantaneous moment in the chaotic

27 occurrence of an arc signature. Nevertheless, Fig. 1 shows the

28 statistical self-similarity of logarithmic fractal subsets of the

29 depicted arc signature.

30 Summarizing the ammonite analogy, the logarithmic nature of

31 the depicted arc spectrum is seen not only in the evolution of

32 the growth spiral 10, but also to the logarithmically progressing

33 length of frequency intervals 12 in terms of wavelength,

34 individually delimited by what corresponds to the above mentioned

35 septa of the ammonite shell. In terms of the electric arc

1   signature, such septa correspond to radial lines 13 denoting
2   certain frequencies so that the intervals 12 between such
3   frequency points are logarithmically distributed along the arc
4   signature in terms of increasing wavelength or decreasing
5   frequency.

6   Fig. 1 also depicts the inverse frequency or 1/f dependency
7   of electric arc signatures in terms of amplitude. In the case
8   of Fig. 1, this shows as an amplitude increasing with wavelength
9   to a value of a_{max}. This is another indication of the fractal
10 nature of electric arcs.

11   On the subject of 1/f-noise, Dres. rer. nat. Heinz-Otto
12 Peitgen and Dietmar Saupe, have pointed out in their work
13 entitled "THE SCIENCE OF FRACTAL IMAGES" (Springer-Verlag, New
14 York, 1988) pp. 39 to 44, that there are no simple mathematical
15 models that produce such noise, other than the tautological
16 assumption of a specific distribution of time constants. This
17 quite unlike to white noise on the one hand and Brownian motion
18 on the other hand.

19   In this respect, they relate the discovery that almost all
20 musical melodies mimic 1/f-noise, and they point out that both
21 music and 1/f noise are intermediate between randomness and
22 predictability, as fractals are intermediate between chaos and
23 order. Indeed, music with its numerous variations on a theme is
24 replete with fractals, and a connoisseur can reliably identify
25 an entire symphony upon hearing only a small portion thereof.
26 Even the smallest phrase reflects the whole. And so it is with
27 electric arc signatures, with such smallest phrase called herein
28 a "fractal subset", and the connoisseur being the arc detector.

29   As the Leitmotif in music, such fractal subset may have the
30 nature of an attractor as a limit figure of fractal iteration,
31 as more fully described below.

32   In terms of indications in Fig. 1, a preferred embodiment
33 of the invention detects the electric arc from a fractal subset
34 below 30 kHz of the wideband range of arc signature frequencies.
35 This includes the above mentioned VLF (very low frequency) range
36 and frequencies below that range.

37   More specifically, an embodiment of the invention restricts

1 fractal subsets from which the electric arc is detected or in
2 which the electric arc is monitored to the ELF (extremely low
3 frequency) band which according to The New IEEE Standard
4 Dictionary of Electrical and Electronics Terms, Fifth Edition
5 (The Institute of Electrical and Electronics Engineers, 1993) is
6 defined as extending from 3 Hz to 3 kHz.

7 Another embodiment of the invention restricts monitored
8 fractals to arc signature frequencies below the voice frequency
9 band (vf) defined in that IEEE Standard Dictionary as extending
10 from 200 Hz to 3500 Hz. In that vein, a further embodiment of
11 the invention restricts monitored fractal subsets to arc
12 signature frequencies below a first harmonic of a standard line
13 frequency in alternating-current power supply systems. An
14 embodiment of the invention even selects the monitored arc
15 signature fractal subset from a frequency band on the order of
16 a standard line frequency (ℓf) in alternating-current power
17 supply systems.

18 In this manner, the invention in its embodiments can select
19 the fractal that will give the best overall performance in a
20 given situation, all the way to the maximum arc signature
21 amplitude of a_{max} for optimum signal-to-noise ratio; with the
22 signal in such case being the 1/f-noise of the arc which we have
23 designated above as λ_w - noise. The noise in the expression
24 "signal-to-noise ratio", on the other hand, includes white noise
25 and Brownian noise, such as produced by the electronic circuits
26 of the arc monitoring apparatus, and extraneous signals that
27 could engender false alarms or readings.

28 Of course, depending on application, there may be goals
29 other than reaching a_{max}, but as Fig. 1 depicts, arc signature
30 amplitudes at various frequency fractals selected pursuant to the
31 subject invention in the larger portion of the outer turn of the
32 growth spiral 10 still are significantly better than what the
33 prior art had to work with.

34 In this respect, selecting from the arc signature a fractal
35 that yields an amplitude of a_{max} or an amplitude comparable
36 thereto according to an embodiment of the invention has another
37 advantage where cross-induction of arc signatures could be a

1   problem.   Take for example the case where several electric
2   circuits are monitored for electric arcs by several corresponding
3   arc detectors, and assume that an arc occurs in one of these
4   circuits and that the arc detector pertaining to that circuit is
5   to respond thereto.

6   Pursuant to what has been said above at and after Equations
7   (1) to (4), by selecting a high-amplitude (i.e. long-wavelength
8   or low-frequency) fractal subset for the arc monitoring process,
9   a preferred embodiment of the invention minimizes if not
10 practically eliminates the prior-art danger of false alarms from
11 cross-induction among independently monitored neighboring
12 circuits.

13   Fig. 2 shows an electric conductor 20 of electric circuitry
14 21 wherein an electric arc 22 occurs.

15   By way of example, the circuitry 21 may be part of a
16 telephone exchange or may be another one of a large variety of
17 electric circuits or loads, including the following examples:

18   In internal combustion engine research, development, and
19 maintenance, it is important to establish and to maintain the
20 optimum spark in each cylinder. A reliable spark monitoring
21 system is therefore highly desirable, if not potentially
22 indispensable in cutting-edge internal combustion engine
23 technology.

24   In a similar vein, electric welding is becoming increasingly
25 robotized and reliable monitoring of the welding arc or spark
26 would greatly benefit research, development and assembly-line
27 quality control and assurance in automated electric arc welding.
28 Moreover, many modern electric spot welding processes rely on
29 immediate application of electric energy to the work pieces to
30 be joined, without intervention of an electric arc. In fact, the
31 occurrence of an electric arc, such as by imperfect contact
32 between the work pieces, degrades the resulting weld in such
33 Joule-effect welding processes. Accordingly, the load at 21 may
34 for instance be a robotic or other spot welding apparatus. In
35 that case, the electric arc monitor could supervise the spot
36 welding process and could signal when substandard welds are being
37 produced by intervening arcing. This, in turn, would signal the

1   need for remedial action, such as including better cleaning of
2   work pieces prior to welding or better compression of the work
3   pieces during welding for more intimate contact.
4   Also, modern descendants of the original electric arc lamp,
5   such as mercury or sodium vapor lamps, could benefit as to
6   research and development and in the maintenance of high-quality
7   performance from reliable arc monitoring systems, as could
8   electric-arc-types of metallurgical and other furnaces.
9   Similarly, arc and spark monitoring systems would be useful
10   to detect and if necessary eliminate faults in electric circuitry
11   and equipment creating radio interference through excessive
12   sparking or arcing.
13   As a further example, some gas heating appliances have
14   gaseous fuel ignitors that work with an electric spark. In such
15   cases, it is often important to know whether the desired spark
16   has occurred for proper ignition, especially if the thermostat
17   is remote from the heating unit. Also, an electric spark monitor
18   would indicate when the igniter is in need for replacement,
19   before breakdown and costly outage occur.
20   Moreover, electric arcs are used in ionizers, such as
21   ammonia arc and other ion generators that are coming into use in
22   satellite thrusters and in propulsion systems in outer space,
23   such as for restabilizing satellites in geostationary orbits or
24   for propelling satellites and space probes on their journey. In
25   such cases, an electric arc monitor would be useful in research,
26   development, maintenance and operation of such ion generators.
27   Alternatively, machinery, circuitry or apparatus at 21 that
28   produces normal sparks in its operation could be monitored for
29   detrimental arcing. One of many examples concerns commutators
30   of electric motors that are often damaged when their carbon
31   brushes wear out, as the rotating commutator then rubs against
32   the metallic brush holder springs. Since such wear is
33   accompanied by heavy arcing, an early detection of such heavy
34   arcing, as distinguished from regular commutator sparking, would
35   signal the need for preventive action and could save the
36   equipment from breakdown and severe damage. The same applies to
37   relays and contactors that generate sparks and arcs in their

1   normal operation, but are subject to excessive arcing in case of
2   malfunction or excessive wear.

3   Similarly, the recurrence of the electric automobile as an
4   environmentally friendlier vehicle than the gasoline-driven
5   automobile or petrol-driven motorcar, renders reliable arc
6   monitoring even more important. In particular, such electric
7   vehicles carry large storage batteries that have to be recharged,
8   typically overnight, and that generate combustible gases, such
9   as oxygen and hydrogen, during such recharging. Electric arcing
10 obviously could be disastrous in such an atmosphere. Accordingly,
11 monitoring that environment for electric arcing and shutting down
12 the charging process and giving an alarm immediately upon
13 detection of arcing, could prevent disaster.

14   In all these cases, the invention selects a fractal subset
15 16 of the signature of the electric arc 22 for the purpose of arc
16 detection. In such selection the invention aims for a relatively
17 long travel of arc signature along the monitored circuit 20
18 (distance between arc 22 and pickup 23), and for low cross-
19 induction among neighboring circuits, including the monitored
20 circuit 20.

21   According to a preferred embodiment of the invention, the
22 fractal subset of arc signature, is selected in a frequency band
23 below 30 kHz, where arc signature amplitudes are higher, arc
24 signature travel along wires (20) is longer, and arc signal
25 cross-induction among separately monitored neighboring circuits
26 (21, 30) is lower, than at higher frequencies.

27   The invention then detects the electric arc 22 from the
28 fractal subset 16 of the arc signature. A preferred embodiment
29 of the invention detects the electric arc 22 from a fractal
30 subset of the arc signature below 30 kHz, such as in the ELF
31 (extremely low frequency) band, defined above as extending from
32 3 Hz to 3 kHz, or even below the voice frequency band (vf)
33 defined above as extending from 200 Hz.

34   By way of example Fig. 3 shows such a fractal subset of the
35 arc signature at 16 within a band 15 illustrated on a logarithmic
36 scale. In practice, selection of such a low-frequency fractal
37 subset 16 avoids false alarms by cross-induction, such as between

1 the circuit 20 where an arc 22 does occur, and any separately
2 monitored neighboring circuits 30, etc., wherein no arc occurs
3 at the moment or, conversely, between any neighboring circuit
4 where an electric arc does occur and is monitored by another
5 monitoring circuit 19, and the circuit 20 when no arc occurs at
6 that point.

7 Selection of such low-frequency fractal subset 16 also
8 permits detection of the arc 22 from a remote location along
9 wires 20 over longer distances than would be possible at high
10 frequencies. Selection of such a low frequency band also yields
11 a high amplitude input signal for the detection process according
12 to the above mentioned $1/f$ or λ_v characteristic of the arc for
13 highest signal-to-noise ratio with lowest exposure to false
14 alarms.

15 Sensitivity to switching transients in telephone exchanges,
16 to multiplexed audio and otherwise, and to harmonics of alterna-
17 ting-current supply frequencies may be practically eliminated,
18 and the permissible travel distance of arc signals between the
19 arc 22 and the pickup 23 may be multiplied as compared to high-
20 frequency detection systems, by selecting the narrower frequency
21 band 15 on the order of a standard line frequency in public
22 alternating-current power supply systems. Preferably, according
23 to that embodiment, the selected narrower frequency band is below
24 the first-order harmonic of that standard line frequency.

25 According to the embodiment illustrated with the aid of Fig.
26 3, the selected arc signature fractal subset may be a filter
27 passband 15, below line frequency, such as below 50 Hz for
28 European-type systems and below 60 Hz for American-type systems.

29 Accordingly, it may be said that arc monitoring according
30 to a preferred embodiment of the invention concentrates on the
31 low end of the arc signature spectrum.

32 The fractal subset of the arc signature 16 or the passband
33 15 from which detection of an arc 22 takes place, covers at least
34 a quarter of a logarithmic decade of the wideband range of
35 frequencies of the electric arc 22.

36 This overcomes a drawback of the prior-art approach
37 manifestation in the above mentioned WO90/04278 that missed the

1   point by limiting the band of detection to within some 20 kHz at
2   some 170 kHz center frequency. This, however, left only a few
3   percent of the arc signature information in the particular
4   logarithmic decade available for detection, considering that a
5   range of 20 kHz in the 170 kHz area is but a small fragment of
6   the particular logarithmic decade that contains the information
7   signifying "arc" as distinguished from other signals.

8   The situation is not much better in the case of most
9   bandpass filter components of the comb filter disclosed in the
10 above mentioned subsequently filed application. All but the first
11 bandpass filter component have center frequencies belonging in
12 effect to the fifth logarithmic decade covering from 100 kHz to
13 one hertz less than 1 MHz. Since all these components have a 50
14 kHz bandwidth, they can only pass a small percentage of the arc
15 signature information in the particular logarithmic decade for
16 detection of an arc as distinguished from other error signals or
17 from picked-up extraneous signals. By rotating detection among
18 the components of its comb filter arrangement, that prior-art
19 proposal even misses an opportunity of making best use of its
20 lowest frequency component in the 55 kHz area.

21   By way of example, the invention may be practiced with the
22 circuitry shown in Fig. 2. In that circuitry an electric arc 22
23 having an arc signature typified by a wideband range of
24 frequencies of a chaotic nature, is detected with the aid of an
25 electric filter 25 having an input 26 coupled to that arc, having
26 a passband corresponding to a fractal subset 16 of the arc
27 signature characterized by relatively long travel along the
28 monitored circuit and low cross-induction among neighboring
29 circuits, and having an output 27 of that fractal subset of arc
30 signature. Chaotic wideband signal detector circuitry having a
31 detector input for that fractal subset 16 of the arc signature
32 may be coupled to that output of the electric filter, such as
33 disclosed in the further course of Fig. 2.
34   The arc signature pickup 23 may be of a conventional kind,
35 such as a clamp-on current transformer terminating into an
36 impedance 24 that may be symbolic of a conventional peak-to-peak

1   limiter for clipping unusually large input transients, such as

2   with the aid of two high-speed diodes connected back to back with

3   one side to ground and a series current limiting resistor.

4   The pickup or transformer 23 may for instance be wound to

5   be sensitive to frequencies in the 25 Hz to 50 Hz range with a

6   minimum of insertion loss. Such transformer 23 may be clamped

7   around the line 20 to be monitored. Hall effect sensors present

8   another example of arc signal pick-ups that may be employed in

9   the practice of the invention, which extends to the use of other

10   sensors of a wired or wireless type. Other monitored circuits

11   30, etc., may be provided with like or similar pickups 123 and

12   monitoring circuitry 19.

13   The picked-up arc signature signal or fractal subset 16 is

14   passed through a lowpass filter 25 having an input 26 connected

15   to the arc signature pickup 13.   In a prototype of this

16   embodiment, the configuration of this filter is that of two

17   cascaded 3rd order Butterworth filters; but other configurations

18   and other kinds of filters may be selected within the scope of

19   the invention.

20   The gain vs. frequency plot of Fig. 3 shows a typical

21   response characteristic 41 of such a filter, having little

22   attenuation in the selected narrower frequency band 15.

23   Within the scope of the invention, the passband 15 could

24   cover an entire logarithmic decade, such as from 10 Hz to 100 Hz.

25   According to an embodiment of the invention the monitored arc

26   signature fractal 16 or passband 15 covers not more than a

27   logarithmic decade of the wideband range of frequencies of the

28   electric arc 22, inasmuch as the decade of from D.C. to 10 Hz is

29   rather a regular decade than a logarithmic decade.

30   In this respect, Fig. 3 shows only about half of a

31   logarithmic decade for the upper portion of the filter

32   characteristic 41 at passband 15. This demonstrably has provided

33   reliable arc detection with the illustrated embodiment of the

34   invention.   Depending on circumstances, the fractal of arc

35   signature 16 may be even less than as illustrated in Fig. 3, but

36   should cover at least a quarter of a logarithmic decade of the

37   wideband range of frequencies of the electric arc, for reliable

1 arc detection with simultaneous exclusion of false alarms.

2   In principle, aspects of the invention herein disclosed can
3 be applied to frequency bands other than the preferred ELF
4 (extremely low frequency) band, and the subject applicants have
5 built models of the circuitry shown in Fig. 2 not only for the
6 ELF band, but also for operation at several kilohertz, as well
7 as in the 10 to 20 kHz region.

8   According to a preferred embodiment, the narrower frequency
9 band 15 or fractal subset 16 is selected where there are less
10 extraneous signals than in a remainder of the wideband range of
11 frequencies of the arc signature.   In this respect, the
12 embodiment illustrated in Fig. 3 shows the narrow frequency band
13 15 as covering from about 10 Hz to less than 50 Hz where there
14 are no significant switching transients in telephone exchanges,
15 effects of multiplexed audio signals, harmonics of alternating-
16 current supply frequencies, signals from control or security
17 systems and radio broadcast signals.   However, not all
18 embodiments of the invention are intended to be limited to
19 operation within and below the very low frequency range.

20   According to Fig. 2, the output 27 of the filter 25 is
21 applied to nonlinear processing in what is herein called a non-
22 linear processor 42.   By way of example, such non-linear
23 processor may comprise a demodulator also called "modulated
24 carrier detector" that demodulates signals passed by the filter
25 25, including picked-up electric arc signature segments with
26 chaotically varying amplitudes and frequencies. This and other
27 aspects of the invention treat a fractal subset of the arc
28 signature as a modulated carrier having a modulation indicative
29 of an electric arc 22, and monitor the electric arc by monitoring
30 one or more modulations on such modulated carrier.

31   Apparatus for monitoring an electric arc having an arc
32 signature typified by a wideband range of frequencies of a
33 chaotic nature in a monitored circuit, include a demodulator or
34 modulated carrier detector such as in the non-linear processor
35 42 having an arc signature input 27 and a carrier modulation
36 output 43.

37   By way of example, the fractal subset of an arc signature

1 may be treated as an amplitude-modulated carrier, and the
2 electric arc may then be monitored by monitoring a modulation of
3 such amplitude-modulated carrier, such as by recovering the
4 modulation on such amplitude-modulated carrier, and by then
5 detecting the amplitude from such recovered modulation.

6   Accordingly, the non-linear processor 42 may be an AM
7 detector or demodulator that in response to chaotically varying
8 amplitudes at 27 produces an AC signal at 43 as a function of
9 such chaotically varying amplitudes. More steady signals
10 erroneously picked up by the circuitry 23 to 27, on the other
11 hand, produce no such AC signal. The non-linear processor 42
12 thus is a first stage that distinguishes picked-up arc signatures
13 from signals stemming from radio or television broadcasts, radio
14 frequency security systems or other sources except electric arcs.

15   The non-linear processor 42 thus in effect treats the
16 picked-up arc signature as an amplitude-modulated or AM carrier
17 whose modulation can be monitored by monitoring a modulation or
18 amplitude of such monitored carrier, such as for detection of an
19 electric arc 22. At least in the case of AM detection, such
20 'modulation' still includes its 'carrier'. Such carrier may be
21 stripped from its modulation by such means as a bandpass filter
22 44 connected to the output 43 of the non-linear processor or AM
23 detector 42. By way of example, the bandpass filter 44 may
24 comprise a 3rd order Butterworth filter, or a filter with a
25 similar response. A preferred response of such filter in
26 principle may follow the characteristic 41 shown in Fig. 3,
27 except that the gain may be adjusted as desired or necessary.
28 By way of example, the filter 44 may pass alternating-current
29 signals of frequencies below 20 or 30 Hz and reject spikes and
30 other fast signals that might be produced or occur within the
31 circuitry up to that point.

32   The recovered modulation signifying "arc" appears at the
33 output 45 of bandpass filter 44.

34   According to an embodiment of this aspect of the invention,
35 combined modulated carrier detectors having arc signature inputs
36 and a combined carrier modulation output may be used in
37 monitoring electric arcs.

1   In this respect such combined modulated carrier detectors
2 may be like kind modulated carrier detectors; such as both AM
3 detectors or both FM detectors. An example of this is shown in
4 Fig. 2 according to which like kind modulated carrier detectors
5 are series connected.

6   In particular, the output 45 of bandpass filter 44 is
7 connected to a second demodulator 46 which, for instance, may be
8 an AM demodulator or detector for producing at its output 47 a
9 signal level varying as a function of picked-up arc signature.

10   Within the scope of the invention, like-kind modulated
11 carrier detectors may be parallel connected, such as within non-
12 linear processor 42.

13   Within the broad aspect of the invention, it should be
14 understood that other types or kinds of demodulation techniques
15 may be used, such as those developed for frequency modulation,
16 phase modulation or carrier-suppressed or single-sideband
17 modulation, for example.

18   Accordingly, the non-linear processor 42 may, for instance,
19 include an FM demodulator which at output 43 produces a signal
20 in response to such chaotic variations of phase or frequency as
21 occurring in an electric arc signature. In this respect, the
22 combined modulated carrier detectors may include different kinds
23 of modulated carrier detectors, such as an FM detector at 42 and
24 an AM detector at 46 connected in series.

25   According to an embodiment of the currently discussed aspect
26 of the invention, an arc signature is treated as a carrier
27 modulated both in a first manner and in a different second
28 manner, and its electric arc is monitored by monitoring first and
29 second modulations of said carrier modulated both in said first
30 manner and in said second manner.

31   By way of example, different kinds of modulated carrier
32 detectors include an AM detector and an FM detector, and such AM
33 detector and FM detector are connected in parallel.

34   By way of example, the non-linear processor 42 may include
35 parallel-connected AM and FM demodulators 412 and 413 having 27
36 as their common input, and having individual outputs connected
37 to an AND-element 414, such as shown in Fig. 4.

1   AND-element 414 only provides an output signal at 43 if both
2 the AM demodulator 412 responds to chaotic amplitude variations
3 of the picked-up signal at 27 and the FM demodulator 413 responds
4 to chaotic phase or frequency variations of that signal at 27.
5   This, then, provides a further safeguard against false
6 alarms from such extraneous signals as AM broadcast or control
7 signals and FM broadcast or control signals, and assures that
8 picked-up signals are only signified as stemming from electric
9 arcs if they display not only the chaotic amplitude variation,
10 but also the chaotic phase or frequency variation, that
11 characterize electric arc signatures.
12   Preferably, full-wave rectification or detection is used at
13 42 and 46 instead of a half-wave rectification or detection, in
14 order to improve the speed of detection. Such increased speed,
15 in turn, permits selection of a lower frequency band, such as 15
16 shown in Fig. 3, where signal-to-noise ratio is at a maximum with
17 extraneous signals 52 being at a minimum, even in the
18 deliberately exaggerated showing of Fig. 3. In other words,
19 selection of full-wave rectification or detection alleviates the
20 tradeoff of lower detection speed at lower detection frequencies.
21 The above mentioned higher and less error-affected sensitivity
22 of detection is thus realized without objectionable delays in
23 detection.
24   The arc-indicative signal resulting at an output 47 from the
25 detection process at 46, is timed and level sensed at 48.
26 Conventional RC-type or other timing circuitry and conventional
27 comparator circuitry may be employed at 47 to prevent the arc
28 detector from responding to switching transients, contact
29 bouncing, ordinary commutator arcing and other transient,
30 harmless arcs, such as more fully discussed herein with respect
31 to Fig. 6. Alarm circuitry 50 thus responds only to arcs that
32 sustain themselves for a given, dangerous period of time.
33   The circuitry 47 may include a conventional resettable
34 latching arrangement for latching in an alarm condition if an arc
35 22 occurs and all detection criteria are met as herein described.
36 Various control circuits may be energized at this point, such as
37 for providing an audible alarm, a remote fire alarm, etc., or for

1   shutting down power in the affected line 20. Since circuits of
2   this kind are known *per se*, only a block 50 has been shown to
3   signify the possible presence of such control and alarm circuits.
4   The embodiment of Fig. 2 elegantly avoids false alarms from
5   extraneous signals, without narrowing the bandwidths of picked-up
6   arc signals to significantly less than a fractal subset
7   containing sufficient arc information. Such avoided extraneous
8   signals for instance include television signals, radio broadcast
9   signals, various control signals, harmonics and other signals
10   that are relatively narrow in bandwidths as compared to the wide
11   band of chaotic arc signals.
12   Some extraneous signals, such as those which are of a
13   chaotic nature themselves, may have to be subjected to some
14   common-mode rejection or other processing in order to avoid
15   confusion thereof with chaotic arc signatures. Such rejection
16   of extraneous signals elegantly comes about when picked-up
17   signals are beat against themselves, such as in the context of
18   the following embodiments of the invention.
19   In this respect, refinements pursuant to embodiments of the
20   invention derive from the arc 22 a fractal arc signature subset
21   16 within a frequency band 15, and convert that fractal arc
22   signature subset 16 to an arc signal 17 in a frequency band 18
23   distinct from that fractal subset or frequency band 15, such as
24   shown in Fig. 3, and detect in that arc signal 17 a chaotic
25   wideband characteristic typical of an electric arc. A preferred
26   embodiment of the invention subjects the fractal subset 16 to a
27   frequency transformation, such as shown at 17 in Fig. 3, and then
28   detects the electric arc 22 from that fractal subset after
29   frequency transformation. By way of example and not by way of
30   limitation, the fractal subset 16 may be added to itself and the
31   electric arc 22 may be detected from the fractal subset added to
32   itself, such as in the manner disclosed in Figs. 3 and 5.
33   In particular, a component 142 of the circuitry shown in
34   Fig. 5 prevents extraneous signals that do occur in the monitored
35   frequency band from affecting the arc detection process.
36   According to that technique, narrow-band extraneous signals in
37   the monitored fractal subset 16 of the arc signature are

1   diminished in energy relative to a remainder of that fractal
2   before detection of the electric arc from that fractal. Such
3   component may be a frequency converter 142 that has converter
4   inputs 127 and 227 for the arc signature fractal subset 16
5   coupled to an output 27 of electric filter circuitry 25, and has
6   a converter output 43 for an arc signature segment 17 in a
7   frequency band 18 distinct from the passband 15 of the filter
8   circuitry 25. A chaotic wideband characteristic typical of an
9   electric arc is then detected from such converted arc signal 17,
10 such as with a chaotic wideband signal detector.
11   By way of example and not by way of limitation, the input
12 and output terminals 26 and 45 may be the same in Figs. 2 and 5,
13 whereby the remainder of the circuit may be the same for Fig. 5
14 as in the apparatus of Fig. 2 more fully described above.
15   The illustrated embodiment of the invention even alleviates
16 the inherent tradeoff of slower detection speed at lower
17 frequencies. In particular, by converting the selected arc
18 signal fractal subset 16 from the lower frequency band 15 to a
19 higher frequency band 18 such as shown in Fig. 3 or higher, the
20 currently discussed embodiment of the invention realizes the
21 detection speed corresponding to the higher frequency band 18 for
22 an arc signature fractal subset 16 stemming from the lower
23 frequency band 15 where there are less extraneous signals and
24 where cross-coupling among circuits is lower and actual travel
25 distance of picked-up arc signals is higher than at frequencies
26 above the band 15. At the same time, the illustrated preferred
27 embodiment of the invention realizes for the higher detection
28 speed associated with the higher frequency band 18 the lower
29 cross-coupling among circuits and the longer possible travel
30 distance along the affected line 20 that are associated with the
31 lower frequency band 15. An arc 22 occurring in line 20 thus may
32 be picked up from such line 20 at a considerable distance from
33 that arc, without a release of any arc alarm condition in
34 neighboring lines that are individually equipped with arc pickups
35 123 and arc monitoring circuits 19 which correspond to the
36 circuitry of Figs. 2, 4, 5 or 6, but in which no arcs are
37 occurring at the time.

1   As already indicated, the passband of the filter circuitry
2   25 may be located where there are less extraneous signals than
3   in a remainder of said wideband range of frequencies. Such
4   passband may be in the ELF (extremely low frequency) band, or
5   even below the vf (voice frequency) band, or below a first
6   harmonic of a standard line frequency in alternating-current
7   power supply systems, or may even be on the order of a standard
8   line frequency in alternating-current power supply systems,
9   and/or may cover at least a quarter of a logarithmic decade of
10 the wideband range of frequencies of the electric arc, so as to
11 provide sufficient information for a reliable detection of the
12 arc signal from that logarithmic decade.

13   The frequency converter 142 of Fig. 5 may constitute the
14 non-linear processor 42 of Fig. 2. By way of example, the
15 component 142 may include a multiplier having first and second
16 inputs 127 and 227 connected to a single line 27 for receiving
17 the filtered picked-up arc signal. This has the net effect of
18 mixing the signal with itself, creating sum and difference
19 products at its output 43. By way of example, the component 142
20 may be a four-quadrant multiplier of the type AD633. However,
21 within the scope of the invention, a diode or non-linear circuit
22 may be used for intermodulation of the selected fractal subset
23 16 with itself.

24   By way of example, Fig. 5 in effect adds the arc signature
25 fractal subset 16 to itself in mixer 142 so as to double the
26 frequency band 15 of that fractal subset as the distinct
27 frequency band 18 of the arc signal 17 which may be somewhat
28 truncated, such as by a subsequent filter 144 at the lower end
29 at that higher band 18. That filter may be similar to the above
30 mentioned filter 44 in the circuit of Fig. 2, but may have a
31 narrower bandpass characteristic, such as shown at 51 in Fig. 3.

32   In apparatus terms, a frequency converter, such as component
33 142, has two converter inputs, such as 127 and 227, for the arc
34 signature fractal subset 16 coupled to the output 27 of the
35 electric filter circuitry 25, and has a converter output 43 of
36 the arc signature signal in a frequency band 18 double or
37 otherwise higher than the frequency band 15 of the arc signature

1 fractal subset.

2 The component 142 in effect dilutes regular, man-made, non-
3 chaotic signals that, if picked up and not diluted, might produce
4 false alarms. The multiplier or similar stage 142 does more than
5 simply double the frequencies of the input. It also beats all
6 the frequencies occurring at one input 127 against all the
7 frequencies occurring at the other input 227. This causes the
8 output to display a summation of all the individual frequencies
9 at one input added and subtracted from all the frequencies at the
10 other input. Since both inputs contain a continuum of
11 frequencies, the result is a very rich mix of frequencies at even
12 higher and lower frequencies than those contained at the inputs.
13 Because a man-made signal is usually a discrete single frequency
14 or at worst a narrow spread of frequencies, such signal does not
15 have the breadth of spectrum to contribute strongly to the output
16 at 43. Such man-made signal constitutes a narrow source beating
17 against the broader noise or arc signature continuum, and the
18 result is a very weak component at the output.

19 In this manner, the relative strength of the continuum
20 spectrum from the arc is enhanced compared to the strength of any
21 discreet or man-made components that are passed by the limiter,
22 such as at 24, or by the filter circuitry. This is the essence
23 of this embodiment's ability to reject signals that would produce
24 false alarms. However, a fluctuating carrier with no noise at
25 the input could still be misidentified as an arc if it has
26 sufficient strength, because even though the relative sensitivity
27 to chaotic noise is greater than to modulated carriers, the
28 latter can still reach the output if they are of sufficient
29 strength, and thus can produce a level that may be mistaken as
30 an arc.

31 Accordingly, the output of the converter or multiplier 142
32 is fed to the input of a bandpass filter 144, that may have a
33 response characteristic 51 as shown in Fig. 3. Response
34 characteristics of the type shown in Fig. 3 at 51 may, for
35 instance, be realized by operational amplifier type of bandpass
36 filters, quartz filters, LC resonance filters, and other
37 circuitry accomplishing such kind of function.

As can be seen, the characteristic 51 displays minimal response to any fundamental frequency passed by the lowpass filter 25, such as in the band 15, and, in our example, displays response only to frequencies of the picked-up arc signature fractal subset 16 whose sum or other modulation product fails in the passband range 18 of the frequency-converted arc signature signal 17.

Bandpass filter 144 will pass only frequency components that are within a few hertz on either side of the passband, such as 80 Hz, for instance. This delivers a sample of the higher frequencies in the output of the multiplier 142 to the next stage 46. Because the passband is above the 50 Hz or other selected cutoff of the first filter 25, this stage 144 is only going to pass signals which have been boosted in the mixing process to frequencies higher than such cutoff. This in effect prevents non-chaotic signals from passing this stage.

In principle, the multiplier or stage 142 should not pass any of the original input frequencies (e.g. below 50 Hz) if there is no direct-current at either input 127 and 227, and if such multiplier or stage 142 is perfectly efficient. However, neither assumption is always correct in practice. Accordingly, use of the higher frequency passband filter 144 provides effective rejection of the unprocessed or unmixed original frequencies.

If a higher band of detection frequencies had been selected within the scope of the invention, such as a band limited between 10 and 20 kHz, as an example, an alternate choice for bandpass center frequency would be at some much lower frequency (i.e. 500 Hz.) detecting a difference component in the output 43 of multiplier 142. This would permit a much wider separation in the responses of the different filters employed in the circuitry, such as filters 25 and 144.

In either case, the frequency conversion or intermodulation at 142 greatly reduces the energy of picked-up extraneous signals 52 in the arc signature segment 16, by intensive common-mode or similar rejection.

The output 43 of the multiplier 142 represents a chaotic frequency sum or difference signal version of the picked-up and

1   filtered chaotic arc signature fractal subset 16.

2   Within the scope of the invention, the component 142 may

3   also include the above mentioned AM or FM detector or the

4   combined AM and FM detectors 412 and 413 of Fig. 4, for instance.

5   In such cases, the detector or detectors detect the amplitude

6   and/or frequency or other type of modulation in the converted arc

7   signature, such as indicated at 17, for arc monitoring purposes.

8   Fig. 6 shows another embodiment of the invention where the

9   energy of extraneous signals is subjected to effective common-

10 mode or similar rejection by pairing inverting and non-inverting

11 amplifiers 242 and 342 with each other. By way of example, the

12 inverting amplifier 242 has an input 327 connected to the output

13 27 of bandpass filter 25, and the non-inverting amplifier 342 has

14 an input 427 connected to that output 27 of the above mentioned

15 bandpass filter 25 through which the picked-up arc signal is

16 processed.

17   The inverting amplifier 242 has an output 421 connected to

18 a mixer 442, and the non-inverting amplifier 342 has an output

19 422 connected to that mixer 442. The non-inverting amplifier 342

20 is in parallel to the inverting amplifier 242, such as seen in

21 Fig. 6.

22   The electric filter 25 in the embodiment of Fig. 6 may be

23 the same as the electric filter 25 in the embodiments of Figs.

24 2 to 5. Such a filter may be split in two, providing between the

25 terminal 26 a first filter for the inverting amplifier 242 and

26 a second filter for the non-inverting amplifier 342. Filter 25

27 may be similarly split in or for the embodiment of Figs. 4 and

28 5 to provide separate filter paths from the input terminal 26 to

29 detectors 412 and 413 or multiplier or frequency converter inputs

30 127 and 227.

31   By way of example, the mixer 442 may be composed of

32 conventional components, such as of two diodes interconnected in

33 an OR-element configuration between input terminals at 421 and

34 422 and the previously mentioned output terminal 43. Within the

35 scope of that embodiment, the component 442 may, however, include

36 a modulator, such as the above mentioned modulator 142. In this

37 respect and in general, the circuitry in Fig. 6 between the

1   filtered arc signature portion or segment at 27 and the terminal
2   43 may correspond to the non-linear processor 42 shown in Fig.
3   2. The output of such processor 42 or 242, 342, and 442 at 43
4   may be filtered or otherwise processed at 244. For example, the
5   circuit 244 may include a bandpass filter corresponding to the
6   bandpass filter 4426 or 144 mentioned above with respect to
7   Figs. 2 to 5. Alternatively or additionally, the component 244
8   in Fig. 6 may include a standard IF amplifier, such as the
9   commercially available 440 Hz IF amplifier to name an example.

10   In method terms, the embodiment of Fig. 6 processes a
11 fractal segment, such as shown at 16, or a higher frequency
12 segment of the arc signature in the two paths 327 and 427 out of
13 phase with each other, and detects the electric arc 22 from such
14 out-of-phase segments or portions of the arc signature.

15   In apparatus terms, the embodiment shown in Fig. 6 has an
16 input 327 of a first phase processor, herein called "inverting
17 amplifier" 242 connected to the electric filter output 27 in a
18 first signal path 327 - 421, and has an input 427 of a second
19 phase processor, herein called "non-inverting amplifier" 342,
20 connected to the electric filter output 27 in a second signal
21 path 427 - 422; with such first and second phase processors being
22 180° or otherwise out of phase with each other.

23   The more the outputs 421 and 422 are out of phase with each
24 other, the greater is the common-mode or similar rejection of
25 extraneous narrow-band signals 52 in the embodiment of Fig. 6.
26 The embodiments of Figs. 2 to 5 thus share with each other a
27 feature according to which the narrow-band extraneous signals,
28 such as mentioned above or shown in Fig. 3 at 52 in a fractal
29 subset 16 or other fractal of the arc signature are diminished
30 in energy relative to a remainder of such fractal subset portion
31 before detection of an electric arc 22 from such fractal subset.

32   At least in the embodiments shown in Figs. 3 and 5, the
33 fractal subset 16 is subjected to a frequency transformation,
34 such as shown in Fig. 3, and an electric arc 22 is detected from
35 such fractal subset after such frequency transformation. By way
36 of example, a fractal subset 16 may be cross-modulated or may be
37 added to itself, such as disclosed above with respect to Fig. 5

1   or as mentioned with respect to Fig. 6, and the electric arc is

2   detected from such cross-modulated or added-to-itself fractal

3   subset. The embodiment of Fig. 4 adds the variant of parallel

4   different kind detection or demodulation, and the embodiment of

5   Fig. 6 adds the variant of out-of-phase processing.

6   In either case, a fractal subset of the arc signature

7   portion may be treated as a modulated carrier having a modulation

8   indicative of any electric arc 22, and such electric arc may be

9   detected from such modulated carrier for further rejections of

10   extraneous signals. The demodulator system disclosed above with

11   respect to Fig. 2 can also be used in the embodiment of Fig. 6,

12   the terminal 47 of which may be the same as the input terminal

13   47 of the time and level sensing and alarm circuitry 48 - 50 in

14   Fig. 2, with respect to which various systems of modulation have

15   been mentioned above.

16   Of course, a wideband signal is not an arc signature unless

17   it displays chaotic frequency changes. Accordingly, a stage

18   including comparator 55, may be provided such as shown in Fig.

19   7 to detect and to display a pickup of a disturbance or signal

20   that is not only wideband in the region of interest, but that is

21   also chaotic in nature as an arc signature is, and that is

22   sustained for a period of time, such as determined by the RC

23   component 58.

24   Fig. 7 is a circuit diagram of an optical indicator of

25   possible or actual arcing that can be used at various stages in

26   the systems of Figs. 2, 4, 5 and 6, according to a further

27   embodiment of the invention.

28   By way of example, indications of the progress of the signal

29   through arc monitoring circuitry may be accomplished with three

30   similar functional blocks or differential indicators of which a

31   prototype is shown in Fig. 7 at 54.

32   Such circuit 54 includes an operational amplifier 55 having

33   its non-inverting input 56 connected to a circuit input 57

34   through a lowpass filter and RC timing component 58 to prevent

35   response to short-term transients. The inverting input 60 of

36   that op amp is connected to comparator level resistors 61 and 62.

1   That op amp 55 has a feedback circuit 64 which may include a
2   feedback capacitor or other impedance 65 and a unidirectional
3   current conducting device, such as shown at 66, for such purposes
4   as noise reduction, prevention of premature or excessive
5   switching. By way of example, the op amp 55 may be of the type
6   LM35BAN.

7   The indicator circuit 54 includes light-emitting diodes or
8   LEDs 68 and 69 switched by transistors 71 and 72 biased through
9   resistors, including series resistors 73 and 74 and a pair of
10   resistors 75 and 76. Transistors 71 and 72 may, for instance,
11   be of the type 2N2222.

12   A resistor 78 connects transistor 72 to the output of the
13   comparator op amp 55. Transistor 71 is normally biased ON
14   through the series-connected resistors 75 and 76. This turns ON
15   the first LED 68 which, for instance, may be a green LED.
16   Conversely, the second LED 69 may be a red LED. However, the
17   second transistor 72 and thus the red LED 69 are biased off at
18   that point.

19   As signals having frequencies in the monitored fractal
20   subset or other band of interest occur at the output 43 of the
21   non-linear processor 42 or modulator 142 or mixer 442 in the
22   embodiments of Figs. 2, 4 and 5, and thereby at the input 57 of
23   the circuit 54 connected thereto, the output of the comparator
24   55 goes positive, turning the transistor 72 ON, and shutting the
25   transistor 71 OFF. This turns the red LED 69 ON and turns the
26   green LED 68 OFF, thereby indicating to an observer that
27   frequencies in the band of interest for arc detection are
28   occurring, such as through a disturbance that may be, but not
29   necessarily is indicative of an electric arc 22. The gain of the
30   circuit 54 may be adjusted to avoid sharp transitions in
31   switching states. This helps a user gain a 'qualitative feel'
32   for the amplitude of the signal at that point by gauging the
33   mixture of red and green LED colors. The unidirectional current
34   conducting device 66 may be omitted, if the circuit of Fig. 7 is
35   so used in any of the circuits of Figs. 2, 4, 5 and 6.

36   Alternatively, the terminal 57 of the display circuit 54 may
37   be connected to the terminal 45 in Figs. 2, 5 or 6, or a

1   duplicate of the circuit shown in Fig. 7 may be so connected to

2   that terminal 45 and thereby to the output of the bandpass filter

3   or IF amplifier 44, 144 or 244.

4   Such display stage 54 then indicates through its red LED an

5   occurrence of wideband signals in a bandwidth of interest, such

6   as in the monitored fractal subset; a well-known criterium of arc

7   signatures. Gain adjustments in such circuit 54 again may give

8   a user a 'qualitative feel' with respect to picked-up wideband

9   signals at that point by gauging the mixture the red and green

10 LED colors.

11   However, a wideband signal is not an arc signature unless

12 it displays chaotic frequency changes. Accordingly, the

13 circuitry shown in Fig. 7 may be used as a final display stage

14 in the monitoring circuits shown in Figs. 2, 4, 5 and 6. For

15 instance, the input terminal 57 of the circuit 54 may be

16 connected to the alarm output terminal 49 shown in Fig. 2. In

17 fact, the circuitry of Fig. 7 from terminal 57 through op amp 55

18 may be used as timing circuit 58 and as comparator 55 in the

19 above mentioned timing and level sensing circuitry 43 shown in

20 Fig. 2.

21   The circuitry 54 may thus be used to detect and to display

22 a pickup of a disturbance or signal that is not only wideband in

23 the region of interest, but that is also chaotic in nature as an

24 arc signature is, and that is sustained for a period of time,

25 such as determined by the RC component 58.

26   As disturbances or signals at wideband frequencies in the

27 range of interest occur and vary chaotically, the output of the

28 comparator 55 at circuitry 48 and terminal 49 goes positive,

29 turning ON the transistor 72, and shutting OFF the transistor 71.

30 This turns ON the red LED 69 and turns OFF the green LED 68,

31 thereby indicating to an observer the occurrence of an arc 22 in

32 line 20.

33   The embodiment shown with the aid of Fig. 7 thus provides

34 a prewarning of a possible electric arc; preferably in two or

35 three stages, culminating in a display of an occurrence of a

36 chaotic wideband signal in a bandwidth of the monitored fractal

37 subset, or otherwise in a bandwidth of interest such as described

1   above in connection with these Figs. 2, 4, 5, 6 and 7.

2   Principles and circuitry herein disclosed may be employed
3   in various arc monitoring functions, such as mentioned above.
4   In the case of such uses as research, development, and
5   maintenance in such areas as internal combustion engines or
6   electric ignition, electric welding, and electric lighting, such
7   as mentioned above, circuitry of the type shown in Fig. 2 may be
8   employed up to the terminal 47, with and without circuitry of the
9   type shown in Figs. 4, 5 and 6. The kind of signal display
10 stages shown in Fig. 7 and more sophisticated signal display and
11 evaluation stages may be used in such cases.

12   By way of further example, Fig. 8 shows a system 80 for
13 monitoring occurrence of sparks aboard aircraft 81, such as
14 electric arcs of the type illustrated at 22 in Fig. 2 or sparks
15 of the type generated by worn and other metal components.

16   In this respect, the Federal Aviation Administration of the
17 United States of America in 1998 has ordered immediate inspection
18 of the center fuel tanks of Boeing 747 jetliners after receiving
19 reports of worn fuel line parts that could impinge so as to
20 generate sparks which could result in fire or explosion,
21 especially in the presence of fuel vapors. Apart from this,
22 fire, explosion and other damage from electric arcs aboard
23 aircraft is also possible, wherefor the expression "spark" in
24 this context is employed generically to cover sparks and electric
25 arcs interchangeably.

26   According to this aspect of the invention, the system 80
27 continually monitors an occurrence of sparks at a first location
28 aboard the aircraft, continually monitors an occurrence of sparks
29 at a second location aboard the aircraft distant from such first
30 location, and establishes in response to such monitoring a record
31 82 of sparks occurring at that first location and a record 83 of
32 sparks occurring at the distant second location aboard the
33 aircraft 81.

34   In this respect, the spark monitoring system 80 aboard
35 aircraft 81 may include a spark monitor 92 at a first location
36 aboard the aircraft, having a first spark signal output 102, a
37 spark monitor 93 at a second location aboard the aircraft distant

1   from that first location, having a second spark signal output

2   103, and a spark signal recorder 97 connected to such first and

3   second spark signal outputs.

4   For better protection, an embodiment of that aspect of the

5   invention continually monitors an occurrence of sparks at a third

6   location aboard the aircraft distant from the first and second

7   locations, and establishes the desired record as a record 82 of

8   sparks occurring at the first location, a record 83 of sparks

9   occurring at the second location, and a record 84 of sparks

10   occurring at the third location aboard the aircraft.

11   In this respect, the spark monitoring system 80 may include

12   a spark monitor 94 at a third location aboard the aircraft

13   distant from the first and second locations, having a third spark

14   signal output 104 connected to the spark signal recorder 97.

15   The embodiment of Fig. 8 also has a spark monitor 95 at a

16   fourth location aboard the aircraft distant from the first,

17   second and third locations, having a fourth spark signal output

18   105 connected to the spark signal recorder 97, and a spark

19   monitor 96 at a fifth location aboard the aircraft distant from

20   the first, second, third and fourth locations, having a fifth

21   spark signal output 106 connected to the spark signal recorder

22   97 of the system 80.

23   By way of example, the embodiment of Fig. 8 has the first

24   spark monitor 92 in a frontal area of the aircraft 81 where an

25   electric drive for retracting and deploying a nosewheel or where

26   other electrical equipment may be located. Fig. 8 also shows a

27   spark monitor 94 at the location of a central fuel tank, and

28   spark monitors 93 and 95 at the location of integral wing fuel

29   tanks. The embodiment of Fig. 8, moreover, has a spark monitor

30   96 at the location of an underfloor cargo or other freight

31   compartment.

32   That much for illustrated examples of spark monitor

33   locations. Deployment and location of spark monitors pursuant

34   to the subject invention logically depends not only on concerns

35   of manufacturers and operators, but also on the nature of the

36   aircraft. Less spark monitors typically would be provided in a

37   small aircraft than in a large airplane. Other desirable

1   locations of spark monitors include main wheel carriage retractor
2   positions, electric cable channels, distribution systems, and
3   other potential sparking areas.
4   In fact, pursuant to a preferred embodiment of the currently
5   disclosed aspect of the invention, the system 80 monitors
6   occurrence of sparks at a multitude of different locations aboard
7   the aircraft, and establishes a record of sparks occurring at
8   such multitude of different locations aboard the aircraft 81.
9   According to an embodiment of the invention, an alarm
10 condition is established in response to occurrence of sparks at
11 at least one of the mentioned locations. Such alarm condition
12 may be visual, audible or in any other form.
13   An alarm device may be connected to at least one of the
14 spark signal outputs 102 to 106. By way of example, Fig. 8 shows
15 a bank of signal lights 98 for signalling detection of sparks at
16 any of the illustrated locations. Alarm conditions signalled by
17 such lights or any other alarm conditions within the scope of the
18 invention may be established during the flight of the aircraft.

19   In this respect and in general, the recorder 97 and the
20 signalling equipment 98 may be located aboard the aircraft 81.
21 For instance, alarm conditions may be displayed to the pilot or
22 pilots during flight or may be established at the end of a flight
23 of that aircraft.
24   In practice, it will be rare that an aircraft is recalled
25 while in flight because of detection of sparks, unless sparking
26 is sudden, intensive and persistent. More typically, the
27 recorder 97 will be a so-called "black box" which in the field
28 of aviation refers to sealed shock-proof units designed to
29 survive an aircrash to be recoverable from the wreck for an
30 inspection of the probable cause of the crash. Existence of such
31 a spark detector "black box" aboard TWA Flight 800 would have
32 gone a long way to indicate the cause of that tragedy and to make
33 aircraft and air travel safer for the future.
34   While such is within the scope of the invention, the main
35 object of the invention is, however, to prevent tragedy
36 effectively. In reality, sparking due to defective conditions

1   will go on for weeks, if not months, before the condition has

2   deteriorated to, or has otherwise reached the point, where an

3   explosion or similar disaster can occur under a coincidence of

4   peculiar circumstances including sparking as one of the factors.

5   Accordingly, a preferred embodiment of the invention

6   establishes a record of occurring sparks on a chart 100 which may

7   be processed in the spark signal recorder 97. Practice of the

8   invention is not limited to any specific recording technique or

9   recorder, but Fig. 8 shows a chart recorder having for instance

10 a chart supply 101 and a chart drive 107 for driving the chart

11 in the direction of an arrow 108.

12   Conventional recording devices 112, 113, 114, 115 and 116,

13 connected to spark signal outputs 102, 103, 104, 105 and 106,

14 respectively, may be employed for establishing records 82, 83,

15 84, 85 and 86, respectively, of sparks occurring at the different

16 locations and detected by spark monitors 92, 93, 94, 95 and 96,

17 respectively.

18   Whilst continuous operation of recorder 97 throughout the

19 flight is within the scope of the invention, an embodiment

20 thereof prefers the recorder to run only when there is at least

21 one spark sensed at any of the locations 92, 93, 94, etc. By way

22 of example, Fig. 8 symbolically shows a logic OR-element 109 as

23 a device for starting the recording medium drive 107 only in

24 response to any one or more detected sparks.

25   In either case, the date and time of occurrence of each

26 sparking preferably is recorded, such as on the chart 100 itself.

27 In this respect and in general, a timing track 117 may be

28 provided on the chart 100. Conventional time keeping and signal

29 generating apparatus 118 may be used for this purpose in

30 combination with the remainder of the system, such as in

31 conjunction with a time signal recording device 119 connected to

32 the time signal generating apparatus 118.

33   The recording medium need not necessarily be a chart, but

34 may be a magnetic, thermoplastic or other recording medium.

35   Spark monitoring pursuant to a preferred embodiment of the

36 invention covers an entire flight of the aircraft 81, and the

37 record or chart 100 is inspected after such flight. Within the

1   scope of the invention, such monitoring covers substantially all

2   flights of the aircraft 81 over a maintenance interval, and the

3   record or chart 100 is made available to maintenance personnel.

4   In practice, an inspector or trained maintenance personnel

5   will be able to tell the need for remedial action before a

6   disaster occurs because of sparking. For instance, a persistent

7   trace 84 will indicate ongoing arcing at the central fuel tank,

8   which will call for prompt remedial action, before such sparking

9   and accompanying conditions reach the point where an explosion

10   or fire is possible.

11   By way of example, records of sparking only at the beginning

12   and at the end of a flight, such as indicated in Fig. 8 at 82 and

13   182 may be due to potential malfunction of landing gear, such as

14   from a landing wheel deployment and retraction motor that is

15   wearing out, or from loose contacts in the electric supply,

16   calling for prompt remedial action.

17   On the other hand, little can be done by way of remedial

18   maintenance if the plane is disastrously hit by lightning.

19   However, lightning 110 in the sky or other atmospheric electric

20   charge concentrations can induce electric charges in the aircraft

21   that may set off arc monitors 92 to 96 without igniting any fuel

22   or otherwise damaging the aircraft. In such cases, all signals

23   98 may light up at once, or all recording devices 112 to 116 may

24   simultaneously produce traces, such as indicated at the level of

25   the reference numeral 83 in Fig. 8. This, then, provides a

26   strong inference that such indicated condition is due to induced

27   atmospheric and similar temporary phenomena, rather than to an

28   ongoing arcing condition at any one location.

29   If, however, a trace occurs and persists such as shown at

30   85 after the atmospheric condition has subsided, then there is

31   a strong inference that some sparking due to atmospheric

32   conditions has affected part of the electrical equipment that

33   ought to be looked into.

34   Also, continuous sparking without apparent reason, such as

35   indicated at 84, or recurring arcing, such as indicated at 86 in

36   Fig. 8, may indicate inadequate grounding or may signify the need

37   for design changes. For instance, one of the problems discovered

1   in the wake of the above mentioned disaster of TWA Flight 800 was
2   that part of air conditioner condenser equipment was located too
3   close to the central fuel tank. As is well known, electric
4   arcing typically is stronger in a dry, hot atmosphere, than in
5   a relatively humid and cool location. Accordingly, design
6   changes should relocate hot parts of air conditioning, heat
7   exchanger and other equipment away from fuel tanks, before a
8   condition arises where fuel ignition is possible from sparking.
9   Various techniques may be employed in the practice of the
10 currently discussed aspect of the invention, and reference may,
11 for example, be had to the accompanying Figs. 1 to 7 and to their
12 description herein, such as for those of the spark detectors 92
13 to 96 which are electric arc detectors.
14   For instance, pursuant to Fig. 6, arc signatures of electric
15 arcs picked up by any of the detectors 92 to 96 may be processed
16 in two paths out of phase with each other, and occurrence of
17 electric arcs may be continually monitored from such out-of-phase
18 portions of the arc signature. In apparatus terms and pursuant
19 to Fig. 6, an electric filter 25 having an input 26 coupled to
20 any of the arc detectors 92 to 96 has a passband corresponding
21 to portions of the arc signature, and has an output 27 for such
22 portions of arc signature. An inverting amplifier 242 has an
23 input 327 connected to the output 27 of electric filter 25, and
24 has an amplifier output 241. A non-inverting amplifier 342 has
25 an input 427 connected to the output 27 of electric filter 25,
26 and has an amplifier output 422. The non-inverting amplifier is
27 in parallel to inverting amplifier 242. A chaotic wideband
28 signal detector 422 has a detector input coupled to amplifier
29 outputs 421 and 422 of the inverting and non-inverting amplifiers
30 for arc detection at 92 to 96, for instance.
31   Moreover, as described above with reference to Fig. 2, arc
32 signatures of electric arcs may be treated as a modulated carrier
33 having a modulation indicative of such electric arcs, and
34 occurrence of these electric arcs at 92 to 96 may be continuously
35 monitored by monitoring a modulation of such modulated carrier.
36   In practice, this will avoid response of arc detectors to
37 signals other than arc signatures. Accordingly, even though many

1   radio frequency signals occur aboard aircraft due to its normal
2   operation, false alarms can be avoided by using techniques herein
3   disclosed. In this respect, a preferred embodiment of the
4   invention monitors electric arcs by monitoring a fractal subset
5   of arc signatures of electric arcs, such as at 92 to 96 in the
6   embodiment of Fig. 8. Application of such fractal concept
7   permits the designer to choose the arc detection frequency band
8   that is least likely to be affected by other frequency spectra
9   occurring aboard aircraft 81 or otherwise. Any and all other
10   features herein disclosed for various arc detectors and monitors
11   may also be used in the system 80 shown in Fig. 8 and in further
12   developments thereof within the scope of the invention.
13   On the other hand, non-electrically generated sparks, such
14   as sparks resulting from mutual impingement of metallic parts of
15   the aircraft, may be detected from spark emanations other than
16   accompanying radio frequency spectra or "signatures".
17   By way of example, reference may be had to European Patent
18   Application 87108089.1, filed 4 June 1987 by BBC Brown Boveri AG,
19   and published on 23 December 1987 under Publication No. 0 249 815
20   and showing optoelectronic transducer systems for detecting
21   electric arcs from their optical emanations. In this respect,
22   optical emanations of sparks may also be detected by optoelectro-
23   nic transducers located near equipment where sparking may occur.
24   In fact, optoelectronic transducers may be employed to detect
25   non-electrical sparks as well as electric arcs in given
26   locations. Fiber optics may be employed in this respect between
27   the likely location of the spark or arc and optoelectronic
28   transducers, such as suggested in that European patent publica-
29   tion. The optoelectronic transducers may be connected to
30   electronic circuitry for generating spark signal outputs in the
31   form of electric signals, such as suggested in, or in references
32   cited in, that European patent publication and its accompanying
33   search report. Electric arc detectors and non-electric spark
34   detectors may be used at different locations aboard the aircraft.
35   This extensive disclosure will render apparent or suggest
36   to those skilled in the art various modifications and variations
37   within the spirit and scope of the invention.

WE CLAIM:

1. In a method of monitoring an electric arc having an arc
signature typefied by a wideband range of frequencies of
a chaotic nature in a monitored circuit,
the improvement comprising in combination:
    selecting a fractal subset of said arc signature
characterized by relatively long travel along said monitored
circuit and low cross-induction among neighboring circuits;
and
    monitoring said electric arc from said fractal subset of
said arc signature.

2. A method as in a claim 1,
wherein:
    said fractal subset is selected from a logarithmic decade
of said wideband range of frequencies.

3. A method as in claim 1,
wherein:
    said fraction covers at least a quarter of a logarithmic
decade of said wideband range of frequencies of the electric
arc.

4. A method as in claim 1,
wherein:
    said fractal subset is selected from a frequency band
below 30 kHz.

5. A method as in claim 1,
wherein:
    said selection of a fractal subset is restricted in
frequency to the ELF (extremely low frequency) band.

6. A method as in claim 1,
wherein:
    said selection of a fractal subset is restricted in
frequency to below the vf (voice frequency) band.

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1   7. A method as in claim 1,
2   wherein:
3   said fractal subset is selected below a first harmonic
4   of a standard line frequency in alternating-current power
5   supply systems.

1   8. A method as in claim 1,
2   wherein:
3   said fractal subset is selected from a frequency band on
4   the order of a standard line frequency in alternating-current
5   power supply systems.

1   9. A method as in claim 1, 2, 3, 4, 5, 6, 7 or 8,
2   wherein:
3   narrow-band extraneous signals in said fractal subset of
4   said arc signature are diminished in energy relative to a
5   remainder of said fractal subset before detection of said
6   electric arc from said fractal subset.

1   10. A method as in claim 1, 2, 3, 4, 5, 6, 7 or 8,
2   wherein:
3   said fractal subset is subjected to a frequency
4   transformation; and
5   said electric arc is detected from said fractal subset
6   after said frequency transformation.

1   11. A method as in claim 10,
2   wherein:
3   said fractal subset is added to itself; and
4   said electric arc is detected from the fractal subset
5   added to itself.

1   12.   A method as in claim 1, 2, 3, 4, 5, 6, 7 or 8,
2   wherein:
3   said fractal subset is processed in two paths out of
4   phase with each other; and
5   said electric arc is monitored from the fractal subset
6   processed in said two paths out of phase with each other.

1   13.   A method as in claim 1, 2, 3, 4, 5, 6, 7 or 8,
2   wherein:
3   said fractal subset is treated as a modulated carrier
4   having a modulation indicative of said electric arc; and
5   said electric arc is monitored by monitoring a
6   modulation of said modulated carrier.

1   14.   A method as in claim 13,
2   wherein:
3   said fractal subset is treated as an amplitude-modulated
4   carrier; and
5   said electric arc is monitored by monitoring a
6   modulation of said amplitude-modulated carrier.

1   15.   A method as in claim 14,
2   wherein:
3   said electric arc is monitored by recovering the
4   modulation on said amplitude-modulated carrier, and by then
5   detecting the amplitude from the recovered modulation.

1   16.   A method as in claim 13,
2   wherein:
3   said fractal subset is treated as a frequency-modulated
4   carrier; and
5   said electric arc is monitored by monitoring a
6   modulation of said frequency-modulated carrier.

1   17.   A method as in claim 13,
2   wherein:
3   said fractal subset is treated as a carrier modulated
4   both in a first manner and in a different second manner;
5   and
6   said electric arc is monitored by monitoring first and
7   second modulations of said carrier modulated both in said
8   first manner and in said second manner.

1   18.   A method as in claim 1, 2, 3, 4, 5, 6, 7 or 8,
2   including:
3   providing a prewarning of a possible electric arc.

1   19.   A method as in claim 16,
2   wherein:
3   said prewarning is provided in stages.

1   20.   A method as in claim 1, 2, 3, 4, 5, 6, 7 or 8,
2   including:
3   displaying an occurrence of signals having frequencies
4   in a bandwidth of said fractal subset.

1   21.   A method as in claim 1, 2, 3, 4, 5, 6, 7 or 8,
2   including:
3   displaying an occurrence of wideband signals in a
4   bandwidth of said fractal subset.

1   22.   A method as in claim 1, 2, 3, 4, 5, 6, 7 or 8,
2   including:
3   displaying an occurrence of a chaotic wideband signal
4   in a bandwidth of said fractal subset.

1   23.   In a method of monitoring an electric arc having an arc
2   signature extending over a wideband range of frequencies of
3   a chaotic nature in a monitored circuit,
4   the improvement comprising in combination:
5   processing portions of said arc signature in two paths
6   out of phase with each other; and
7   monitoring said electric arc from said out of phase
8   portions of said arc signature.

1   24.   In a method of monitoring an electric arc having an arc
2   signature extending over a wideband range of frequencies of
3   a chaotic nature in a monitored circuit,
4   the improvement comprising in combination:
5   treating said arc signature as a modulated carrier
6   having a modulation indicative of said electric arc; and
7   monitoring said electric arc by monitoring a modulation
8   of said modulated carrier.

1   25.   A method as in claim 24,
2   wherein:
3   said arc signature is treated as an amplitude-modulated
4   carrier; and
5   said electric arc is monitored by monitoring a
6   modulation of said amplitude-modulated carrier.

1   26.   A method as in claim 25,
2   wherein:
3   said electric arc is monitored by recovering the
4   modulation on said amplitude-modulated carrier, and by then
5   detecting the amplitude from the recovered modulation.

1   27.   A method as in claim 24,
2   wherein:
3   said arc signature is treated as a frequency-modulated
4   carrier; and
5   said electric arc is monitored by monitoring a modulation
6   of said frequency-modulated carrier.

1   28.   A method as in claim 24,
2   wherein:
3   said arc signature is treated as a carrier modulated
4   both in a first manner and in a different second manner;
5   and
6   said electric arc is monitored by monitoring first and
7   second modulations of said carrier modulated both in said
8   first manner and in said second manner.

1   29.   In apparatus for monitoring an electric arc having an arc
2   signature typified by a wideband range of frequencies of
3   a chaotic nature in a monitored circuit,
4   the improvement comprising in combination:
5   an electric filter having an input coupled to said
6   arc, having a passband corresponding to a fractal subset of
7   said arc signature characterized by relatively long travel
8   along said monitored circuit and low cross-induction among
9   neighboring circuits, and having an output for said fractal
10   subset of arc signature; and
11   a chaotic wideband signal detector having a detector
12   input for said fractal subset of said arc signature coupled
13   to said output of the electric filter.

1   30.   Apparatus as in claim 29,
2   wherein:
3   said passband is in a logarithmic decade of said
4   wideband range of frequencies.

1   31.   Apparatus as in claim 29,
2   wherein:
3   said passband is below 30 kHz.

1   32.   Apparatus as in claim 29,
2   wherein:
3   said passband is where there are less extraneous signals
4   than in a remainder of said wideband range of frequencies.

1   33. Apparatus as in claim 29,
2   wherein:
3   said passband is in the ELF (extremely low frequency)
4   band.

1   34. Apparatus as in claim 29,
2   wherein:
3   said passband is below the vf (voice frequency) band.

1   35. Apparatus as in claim 29,
2   wherein:
3   said passband is below a first harmonic of a standard
4   line frequency in alternating-current power supply systems.

1   36. Apparatus as in claim 29,
2   wherein:
3   said passband is on the order of a standard line
4   frequency in alternating-current power supply systems.

1   37. Apparatus as in claim 29,
2   wherein:
3   said passband covers at least a quarter of a logarithmic
4   decade of said wideband range of frequencies of the electric
5   arc.

1   38. Apparatus as in claim 29,
2   wherein:
3   said passband covers not more than a logarithmic decade
4   of said wideband range of frequencies of the electric arc.

1   39. Apparatus as in claim 29,
2   including:
3   an inverting amplifier having an input connected to said
4   output of said electric filter, and having an amplifier
5   output connected to said detector input; and
6   a non-inverting amplifier having an input connected to
7   said output of said electric filter, and having an amplifier
8   output connected to said detector input.

1   40. Apparatus as in claim 29,
2   wherein:
3   said chaotic wideband signal detector includes a
4   modulated carrier detector coupled to said output of the
5   electric filter.

1   41. Apparatus as in claim 40,
2   wherein:
3   said modulated carrier detector is an AM detector.

1   42. Apparatus as in claim 40,
2   wherein:
3   said modulated carrier detector is an FM detector.

1   43. Apparatus as in claim 40,
2   wherein:
3   said chaotic wideband detector includes combined
4   modulated carrier detectors.

1   44.   Apparatus as in claim 29, 30, 31, 32, 33, 34, 35, 36, 37,
2   38, 39, 40, 41, 42 or 43,
3   including:
4   an energy converter having a converter input for said
5   fractal subset and for narrow-band extraneous signals in
6   said arc signature segment coupled to said output of the
7   electric filter, and having a converter output for said arc
8   signature segment and for narrow-band extraneous signals of
9   diminished energy relative to the fractal subset and being
10   connected to said chaotic wideband signal detector.

1   45.   Apparatus as in claim 29, 30, 31, 32, 33, 34, 35, 36, 37,
2   38, 39, 40, 41, 42 or 43,
3   including:
4   a frequency converter having a converter input for said
5   fractal subset coupled to said output of the electric filter
6   circuitry, and having a converter output for said fractal
7   subset in a frequency band distinct from said passband and
8   being connected to said chaotic wideband signal detector.

1   46.   Apparatus as in claim 29, 30, 31, 32, 33, 34, 35, 36, 37,
2   38, 39, 40, 41, 42 or 43,
3   including:
4   a frequency converter having two converter inputs for
5   said fractal subset coupled to said output of the
6   electric filter, and having a converter output for said
7   fractal subset in a frequency band double the frequency band
8   of said fractal subset as the distinct frequency band of
9   said arc signal and being connected to said chaotic wideband
10   signal detector.

1   47.   Apparatus as in claim 29, 30, 31, 32, 33, 34, 35, 36, 37,
2   38, 39, 40, 41, 42 or 43,
3   including:
4   a modulator having a modulator input for said fractal
5   subset coupled to said output of the electric filter, and
6   having a modulator output for a modulated carrier having a
7   modulation indicative of said electric arc connected to said
8   chaotic wideband signal detector;
9   said chaotic wideband signal detector including a
10   modulation detector.

1   48.   Apparatus as in claim 29, 30, 31, 32, 33, 34, 35, 36, 37,
2   38, 39, 40, 41, 42 or 43,
3   including:
4   a modulator having a modulator input for said fractal
5   subset coupled to said output of the electric filter, and
6   having a modulator output for an amplitude-modulated carrier
7   having an amplitude modulation indicative of said electric
8   arc connected to said chaotic wideband signal detector;
9   said chaotic wideband signal detector including an
10   amplitude-modulation detector.

1   49.   Apparatus as in claim 48,
2   wherein:
3   said amplitude-modulation detector includes a first
4   stage recovering the modulation on said amplitude-modulated
5   carrier, and a second stage detecting from the recovered
6   modulation an amplitude indicative of said arc signature.

1   50.   Apparatus as in claim 29, 30, 31, 32, 33, 34, 35, 36, 37,
2   38, 39, 40, 41, 42 or 43,
3   including:
4   an electric arc prewarning indicator coupled to said
5   electric filter.

1   51. Apparatus as in claim 29, 30, 31, 32, 33, 34, 35, 36, 37,
2   38, 39, 40, 41, 42 or 43,
3   including:
4   an electric arc prewarning indicator coupled to said
5   chaotic wideband signal detector.

1   52. Apparatus as in claim 29, 30, 31, 32, 33, 34, 35, 36, 37,
2   38, 39, 40, 41, 42 or 43,
3   including: `
4   a wideband signal indicator coupled to said chaotic
5   wideband signal detector.

1   53. Apparatus as in claim 52,
2   wherein:
3   said indicator is a wideband chaotic signal indicator
4   coupled to said chaotic wideband signal detector.

1   54. In apparatus for monitoring an electric arc having an arc
2   signature typified by a wideband range of frequencies of
3   a chaotic nature in a monitored circuit,
4   the improvement comprising in combination:
5   an electric filter having an input coupled to said
6   arc, having a passband corresponding to portions cf said arc
7   signature, and having an output for said portions of arc
8   signature;
9   an inverting amplifier having an input connected to said
10   output of said electric filter, and having an amplifier
11   output;
12   a non-inverting amplifier having an input connected to
13   said output of said electric filter, having an amplifier
14   output, and being in parallel to said inverting amplifier;
15   and
16   a chaotic wideband signal detector having a detector
17   input coupled to said amplifier outputs of said inverting
18   and non-inverting amplifiers.

1 · 55. In apparatus for monitoring an electric arc having an arc
2   signature typified by a wideband range of frequencies of
3   a chaotic nature in a monitored circuit,
4   the improvement comprising in combination:
5   a modulated carrier detector having an arc signature
.6   input and a carrier modulation output.

1   56. Apparatus as in claim 55,
2   wherein:
3   said modulated carrier detector is an AM detector.

1   57. Apparatus as in claim 55,
2   wherein:
3   said modulated carrier detector is an FM detector.

1   58. In apparatus for monitoring an electric arc having an arc
2   signature typified by a wideband range of frequencies of
3   a chaotic nature in a monitored circuit,
4   the improvement comprising in combination:
5   combined modulated carrier detectors having arc
6   signature inputs and a combined carrier modulation output.

1   59. Apparatus as in claim 58,
2   wherein:
3   said combined modulated carrier detectors are like kind
4   modulated carrier detectors.

1   60. Apparatus as in claim 59,
2   wherein:
3   said like kind modulated carrier detectors are series
4   connected.

1   61. Apparatus as in claim 59,
2   wherein:
3   said like kind modulated carrier detectors are parallel
4   connected.

1   62. Apparatus as in claim 58,
2   wherein:
3   said combined modulated carrier detectors include
4   different kinds of modulated carrier detectors.

1   63. Apparatus as in claim 62,
2   wherein:
3   said different kinds of modulated carrier detectors
4   include an AM detector and an FM detector.

1   64. Apparatus as in claim 63,
2   wherein:
3   said AM detector and FM detector are connected in
4   parallel.

1   65. Apparatus as in claim 64,
2   including:
3   an AND-element having inputs connected to said AM
4   detector and said FM detector, and having an output as said
5   combined carrier modulation output.

1   66. A method of monitoring occurrence of sparks aboard aircraft,
2   comprising in combination:
3   continually monitoring an occurrence of sparks at a first
4   location aboard the aircraft;
5   continually monitoring an occurrence of sparks at a
6   second location aboard the aircraft distant from said first
7   location; and
8   establishing in response to said monitoring a record of
9   sparks occurring at said first location and a record of
10   sparks occurring at said distant second location aboard the
11   aircraft.

67. A method as in claim 66,
    including:
        continually monitoring an occurrence of sparks at a third
    location aboard the aircraft distant from said first and
    second locations; and
        establishing said record as a record of sparks occurring
    at said first location, a record of sparks occurring at said
    second location, and a record of sparks occurring at said
    third location aboard the aircraft.

68. A method as in claim 66 or 67,
    wherein:
        said record is established on a chart.

69. A method as in claim 66 or 67,
    wherein:
        said monitoring covers an entire flight of said aircraft;
    and
        said record is inspected after said flight.

70. A method as in claim 66 or 67,
    wherein:
        said monitoring covers substantially all flights of said
    aircraft over a maintenance interval; and
        said record is made available to maintenance personnel.

71. A method as claimed in claim 66 or 67,
    wherein:
        an alarm condition is established in response to
    occurrence of sparks at at least one of said locations.

72. A method as in claim 71,
    wherein:
        said alarm condition is established during a flight of
    said aircraft.

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1   73.   A method as in claim 71,
2         wherein:
3             said alarm condition is established at the end of a
4         flight of said aircraft.


1   74.   A method as in claim 66 or 67,
2         wherein:
3             said sparks are electric arcs;
4             arc signatures of said electric arcs are processed
5         in two paths out of phase with each other; and
6             occurrence of electric arcs is continually monitored
7         from said out of phase portions of said arc signature.


1   75.   A method as in claim 66 or 67,
2         wherein:
3             said sparks are electric arcs;
4             arc signatures of said electric arcs are treated as a
5         modulated carrier having a modulation indicative of said
6         electric arc; and
7             occurrence of electric arcs is continuously monitored
8         by monitoring a modulation of said modulated carrier.


1   76.   A method as claimed in claim 66 or 67,
2         wherein:
3             said sparks are electric arcs;
4             said electric arcs are monitored by monitoring a fractal
5         subset of arc signatures of said electric arcs.


1   77.   A spark monitoring system aboard aircraft,
2         comprising in combination:
3             a spark monitor at a first location aboard the
4         aircraft, having a first spark signal output;
5             an spark monitor at a second location aboard the
6         aircraft distant from said first location, having a second
7         spark signal output; and
8             a spark signal recorder connected to said first and
9         second spark signal outputs.
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1   78.   A system as in claim 77,
2   including:
3   a spark monitor at a third location aboard the aircraft
4   distant from said first and second locations, having a third
5   spark signal output connected to said spark signal recorder.

1   79.   A system as in claim 77 or 78,
2   wherein:
3   said record is a chart recorder.

1   80.   A system as claimed in claim 77 or 78,
2   including:
3   an alarm device connected to at least one of said
4   spark signal outputs.

1   81.   A system as in claim 77 or 78,
2   including:
3   electric arc monitors as said spark monitors;
4   an electric filter in at least one of said electric arc
5   monitors, having a passband corresponding to a fractal
6   subset of said arc signature, and having an output for said
7   fractal subset of arc signature; and
8   a chaotic wideband signal detector having a detector
9   input for said fractal subset of said arc signature coupled
10   to said output of the electric filter.

1   82. A system as in claim 77 or 78,
2   including:
3   electric arc monitors as said spark monitors;
4   an electric filter in at least one of said electric arc
5   monitors, having a passband corresponding to portions of
6   a signature of a monitored arc, and having an output for
7   said portions of arc signature;
8   an inverting amplifier having an input connected to said
9   output of said electric filter, and having an amplifier
10   output;
11   a non-inverting amplifier having an input connected to
12   said output of said electric filter, having an amplifier
13   output, and being in parallel to said inverting amplifier;
14   and
15   a chaotic wideband signal detector having a detector
16   input coupled to said amplifier outputs of said inverting
17   and non-inverting amplifiers.

1   83. A system as in claim 77 or 78,
2   for monitoring an electric arc having an arc signature
3   typified by a wideband range of frequencies of a chaotic
4   nature in at least one of said electric arc monitors,
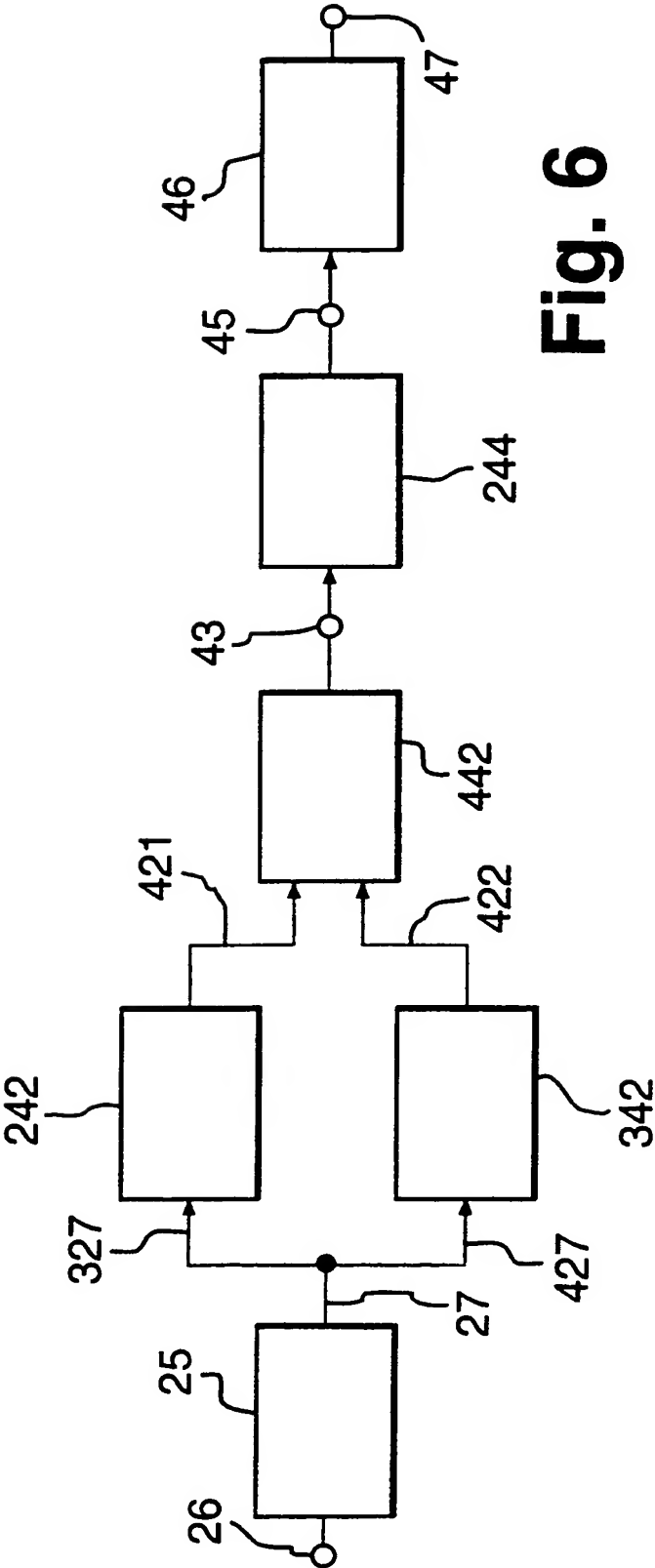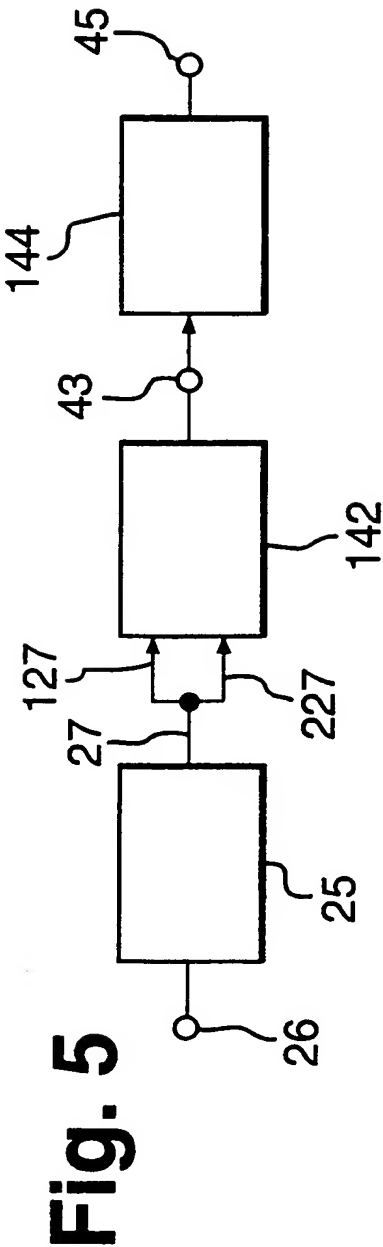5   the improvement comprising in combination:
6   a modulated carrier detector having an arc signature
7   input and a carrier modulation output.
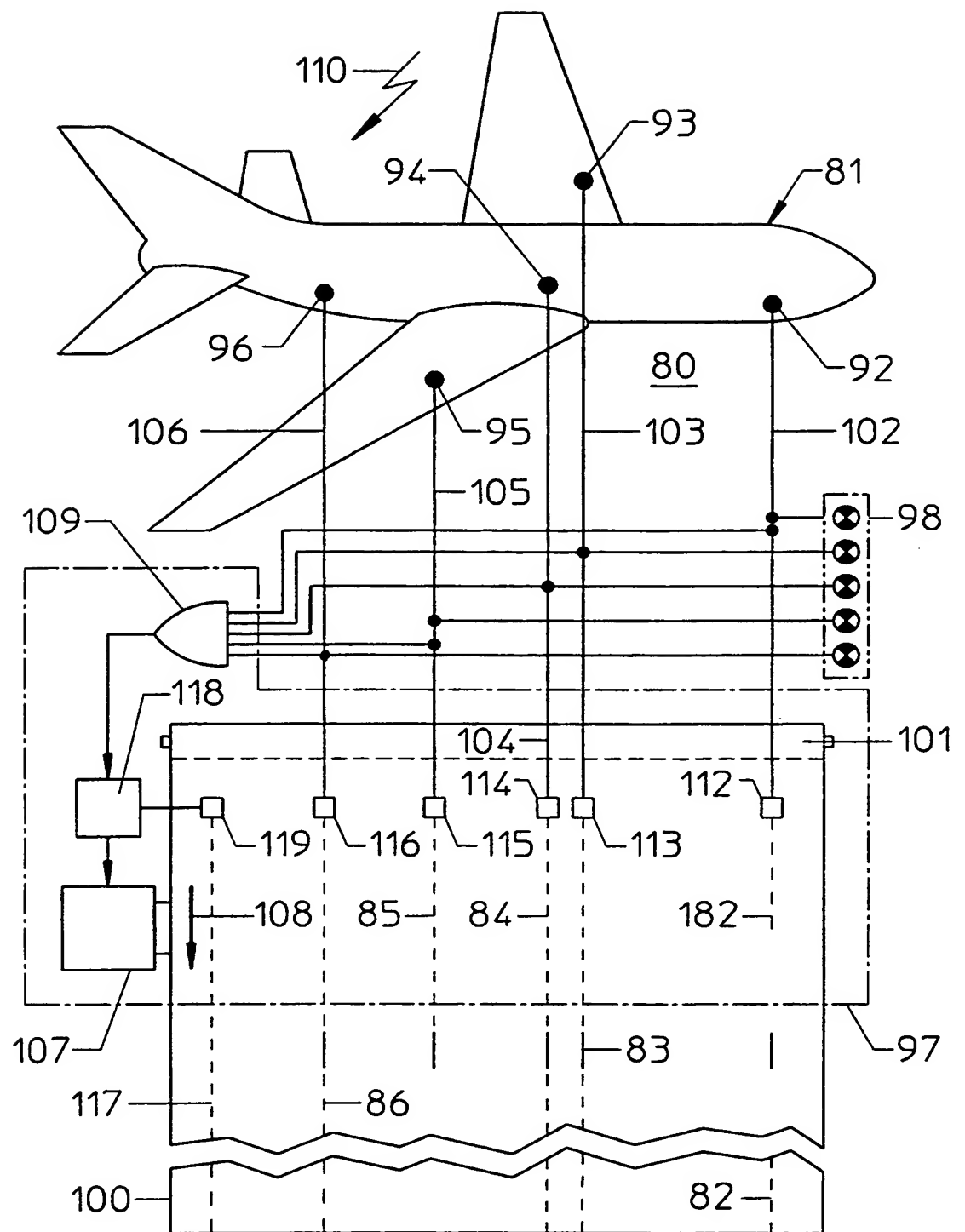
Fig. 1

Fig. 2

Fig. 3

Fig. 4

Fig. 7

Fig. 5
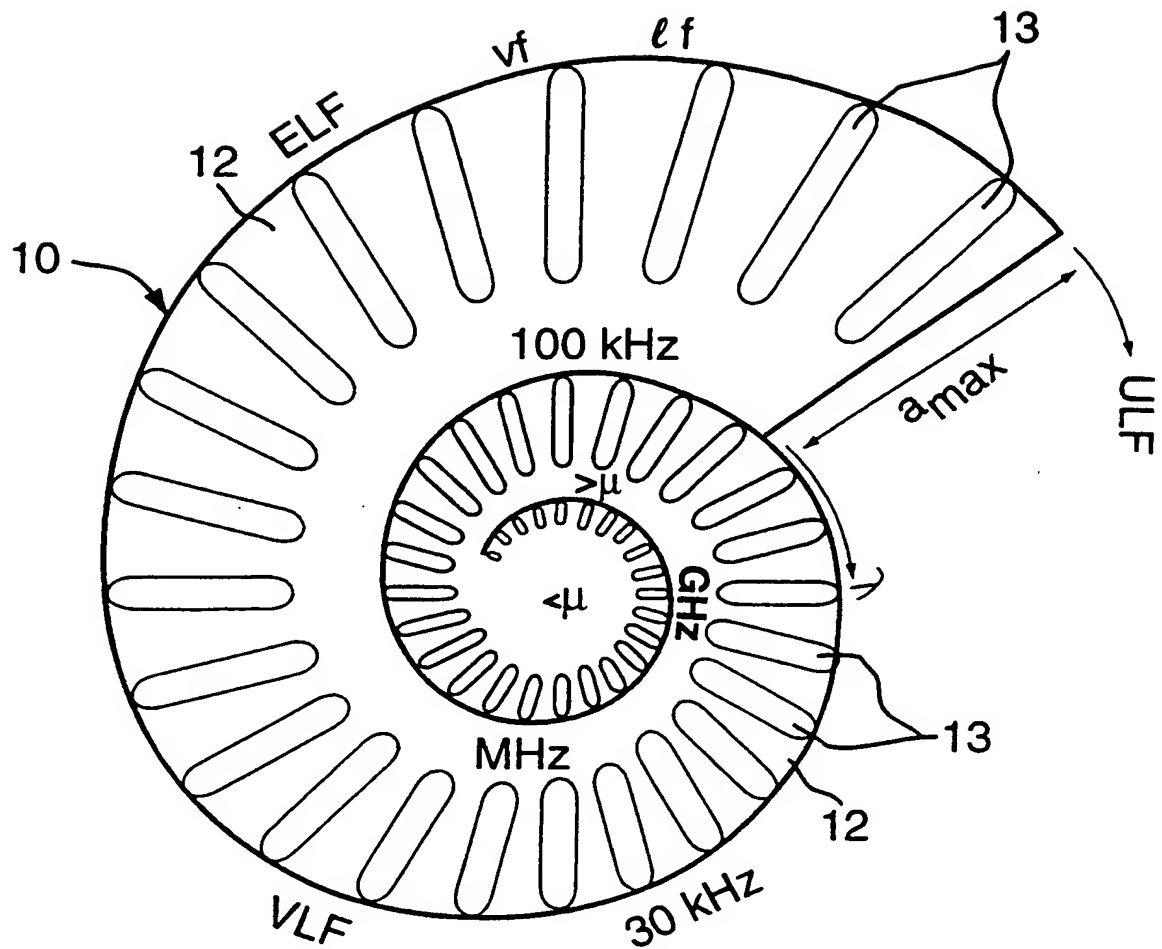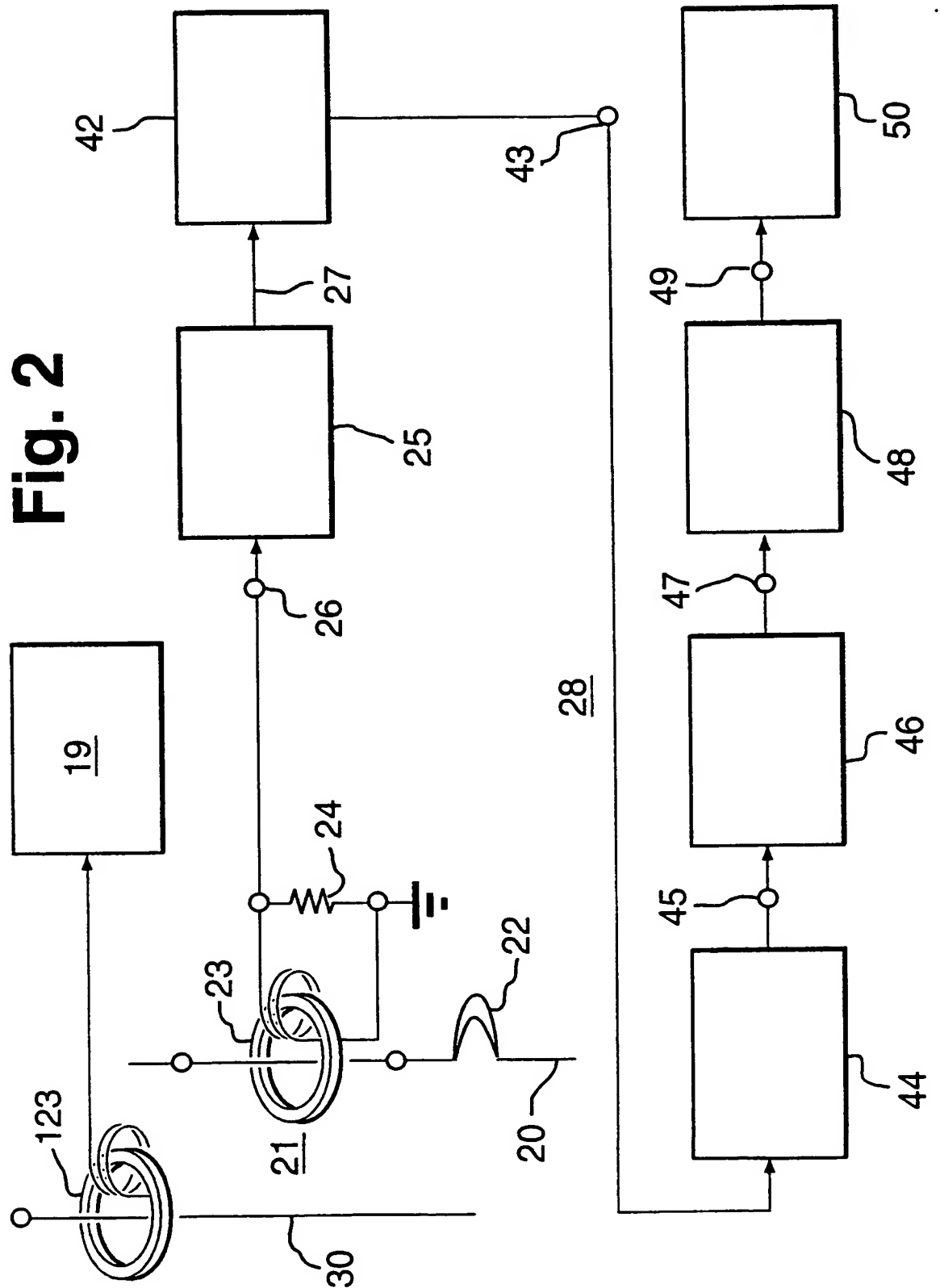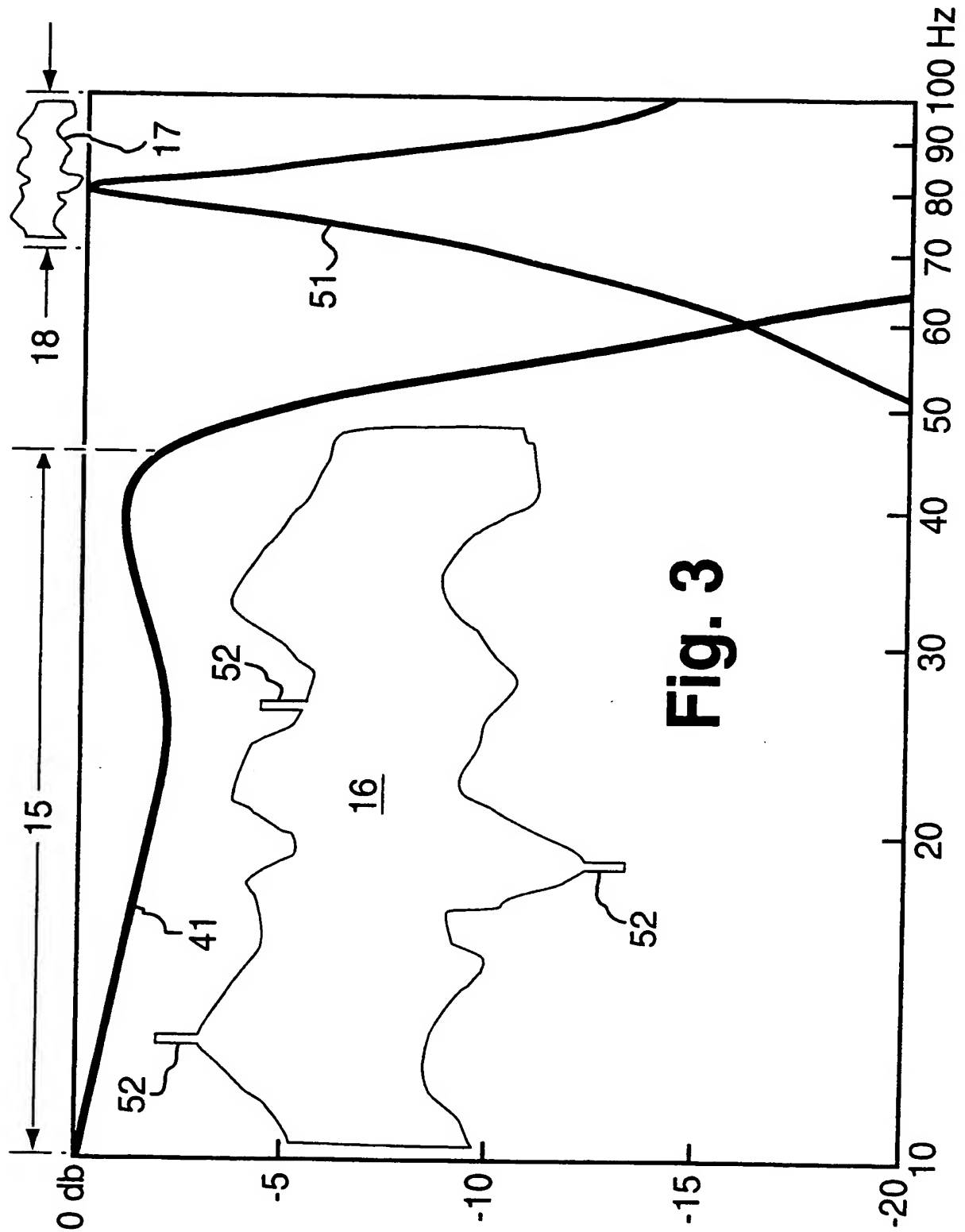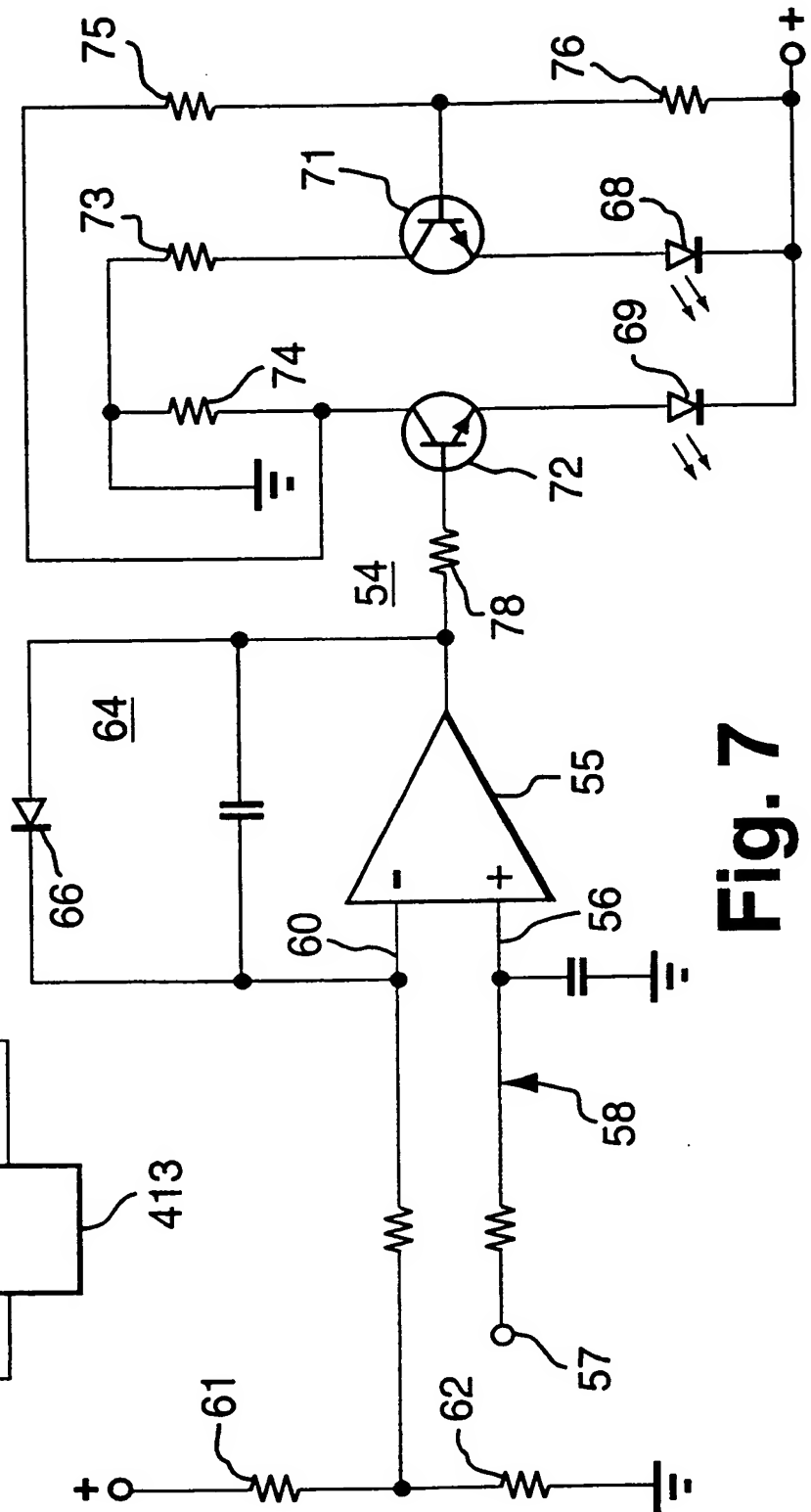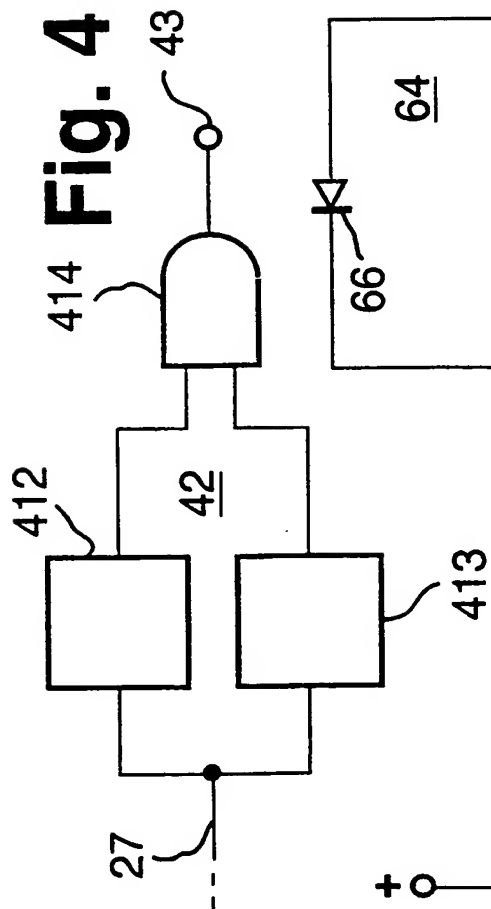
Fig. 6

Fig. 8

INTERNATIONAL SEARCH REPORT

	International application No.
	PCT/US98/16521

A. CLASSIFICATION OF SUBJECT MATTER

IPC(6) :G01R 23/00
US CL :702/76

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 702/76

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

APS

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 5,353,233 A (OIAN et al) 04 October 1994, col. 8, lines 43-50, col. 8, lines 60-64), col. 10, lines 51-55),	1-3, 23, 24-30

	Further documents are listed in the continuation of Box C.		See patent family annex.

*	Special categories of cited documents:	"T"	later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"A"	document defining the general state of the art which is not considered to be of particular relevance		
"E"	earlier document published on or after the international filing date	"X"	document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"L"	document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)	"Y"	document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"O"	document referring to an oral disclosure, use, exhibition or other means		
"P"	document published prior to the international filing date but later than the priority date claimed	"&"	document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
07 NOVEMBER 1998	2 9 DEC 1998

Name and mailing address of the ISA/US	Authorized officer
Commissioner of Patents and Trademarks Box PCT Washington, D.C. 20231	THOMAS PEESO Joni Hill
Facsimile No. (703) 305-3230	Telephone No. (703) 305-9784

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